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GATECYCLE SIMULATOR AND ITS APPLICATIONS
SIMULÁTOR GATECYCLE A JEHO APLIKACE

MASTER'S THESIS
DIPLOMOVÁ PRÁCE

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VEDOUCÍ PRÁCE

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BRNO UNIVERSITY OF TECHNOLOGY FACULTY OF MECHANICAL ENGINEERING

Master's Thesis Assignment

Institut:	Institute of Process Engineering
Student:	**Bc. Adam Svoboda**
Degree programm:	Mechanical Engineering
Branch:	Process Engineering
Supervisor:	**doc. Ing. Zdeněk Jegla, Ph.D.**
Academic year:	2018/19

As provided for by the Act No. 111/98 Coll. on higher education institutions and the BUT Study and Examination Regulations, the director of the Institute hereby assigns the following topic of Master's Thesis:

GateCycle simulator and its applications

Brief description:

The work is focused on study and practical application of software system GateCycle for process and power-plant systems simulation. Realization of simulations of selected power systems and verification of ability, properties and utilization this optimization and diagnostic software are the main goals of the work.

Master's Thesis goals:

1. Get acquainted with GateCycle software and its environment and introduce it in a diploma work on a simple illustrative case.
2. Use the GateCycle software to simulate a selected power unit and compare obtained results with available operating or projection data.
3. Perform a comprehensive assessment of achieved results and discuss the findings, features and capabilities of the software and related aspects.

Recommended bibliography:

GateCycle Installation Quick Start Quide, GE Energy, USA, 2010.

VDI-Gesselschaft Verfahrenstechnik und Chemieingenieurwesen Ed., VDI Heat Atlas, Second Edition, Springer-Verlag Berlin Heidelberg, 2010.

Students are required to submit the thesis within the deadlines stated in the schedule of the academic year 2018/19.

In Brno, 24. 10. 2017

L. S.

prof. Ing. Petr Stehlík, CSc., dr. h. c. Director of the Institute	doc. Ing. Jaroslav Katolický, Ph.D. FME dean

Abstract

The major goal of this thesis is to get acquainted with General Electric Company GateCycle software and its subsequent application to simulate an industrial steam boiler producing 120 t of steam per hour. Thesis is designed in a form of teaching material which might be used in process engineering course focused on the simulation software.

The first part of the thesis is dedicated to brief theory about simulation software and lists a few of the most well-known process engineering simulation programs. The second part is written in a form of GateCycle manual. It shortly introduces software workspace and interface, demonstrates how to build and run a simulation model, supply input data and make reports. The third part is practical, selected industrial steam boiler is presented and subsequently its simulation model is built. It is designed in a form of “step-by-step” guide explaining how to set up the boiler model and what data are input into specific process apparatus. Boiler is simulated in 3 regimes, using either natural gas, heavy fuel oil or tar heating oil as a fuel and it operates in slightly various process conditions. In the end, calculated fuel consumptions are compared to real operating data and accuracy of GateCycle software calculations is evaluated in these specific cases.

Keywords

Process engineering, simulation software, GateCycle, manual, guide, industrial steam boiler, natural gas, heavy fuel oil, tar heating oil

Abstrakt

Hlavná náplň tejto práce je oboznámenie so softvérom GateCycle od spoločnosti General Electric a jeho následná aplikácia na simulovanie industriálneho parného kotla produkujúceho 120 t pary za hodinu. Dizajn práce je vo forme výučbového materiálu, ktorý môže byť použitý vo výuke predmetu procesného inžinierstva zameraného na simulačné softvéry.

Prvá časť práce je venovaná krátkej teórii o simulačných softvéroch a uvádza niekoľko najznámejších procesných inžinierskych simulačných programov. Druhá časť je napísaná formou GateCycle manuálu. V krátkosti predstavuje pracovné prostredie a rozhranie softvéru, demonštruje ako vytvoriť a spustiť simulačný model, zadať vstupné dáta a vytvoriť reporty. Tretia časť práce je praktická, vybraný industriálny parný kotol je prezentovaný a následne je vybudovaný jeho simulačný model. Táto časť je vytvorená vo forme príručky „krok za krokom“ vysvetľujúcej ako vytvoriť model kotla a aké dáta boli zadané do jednotlivých procesných aparátov. Kotol je simulovaný v 3 režimoch, využívajúc zemný plyn, ťažký vykurovací olej, či dechtovú vykurovaciu zmes ako palivo a je prevádzkovaný za mierne rozličných procesných podmienok. V závere sú vypočítané spotreby paliva porovnané s reálnymi prevádzkovými dátami a je vyhodnotená presnosť výpočtov softvéru GateCycle v týchto konkrétnych prípadoch.

Kľúčové slová

Procesné inžinierstvo, simulačný softvér, GateCycle, manuál, príručka, industriálny parný kotol, zemný plyn, ťažký vykurovací olej, dechtová vykurovacia zmes

Bibliographic citation

SVOBODA, A. *GateCycle simulator and its applications.* Brno: Brno University of Technology, Faculty of Mechanical Engineering, 2018. 82 p. Supervised by doc. Ing. Zdeněk Jegla, Ph.D.

Declaration

I declare that I have personally elaborated the thesis "GateCycle simulator and its applications" independently, under the supervision of my master’s thesis supervisor, doc. Ing. Zdeněk Jegla, Ph.D. and with the use of the sources which are all listed in the bibliography section.

In Brno 4.10.2018

Adam Svoboda

Acknowledgement

I would like to express gratitude to my master's thesis supervisor doc. Ing. Zdeněk Jegla, Ph.D. for his valuable advice and his willingness to help at any time. I would like to express my thanks to prof. Ing. Petr Stehlík, CSc., dr. h. c., as well. He directed my steps towards Institute of Process Engineering and has granted me favours many times since then. Finally, I am most grateful to my parents who supported me on every step of my "journey for the title".

Content

1 Introduction

Process engineering is a significantly broad field applicable in many industries such as chemical, pharmaceutical, oil and gas, food or power generation industry. Generally, one could say that its main task is a systematic approach to designing and operating complicated engineering processes in industrial production. Application of many kinds of process equipment (e.g. heat exchangers, furnaces, steam boilers, distillation columns, etc.) is often being involved.

This field concerns process development of transforming raw materials into value-added products by design, control and intensification of chemical, physical, and biological processes. Main goals are the maximisation of energy utilization (waste heat usage, process integration), cutting of emissions and optimisation of investment and operating costs. Block diagram showing examples of process engineering applications is being shown in Figure 1.

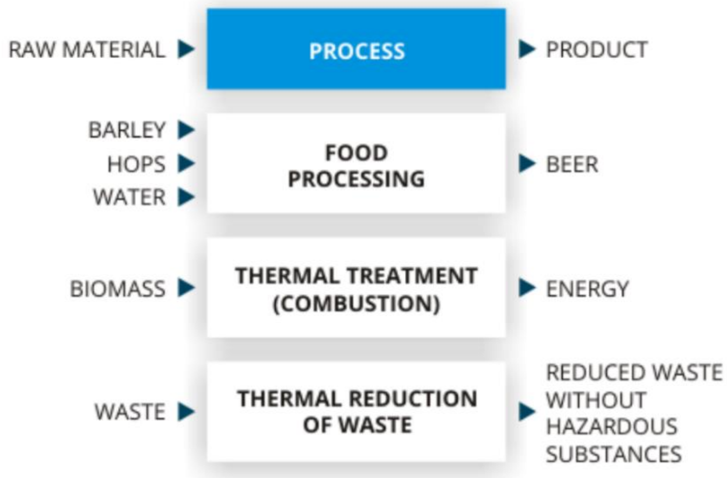


Figure 1: Block diagram of process engineering applications [1]

It is obvious from Figure 1 that most of the processes are highly energy demanding which means that it is necessary to design them in the most effectively feasible way. This is the reason why we use simulations - to minimise process negative environmental impact by energy wastage, while achieving the best financial outcome.

1.1 What is a simulation?

There are plenty of possible ways how to define the term “simulation” depending on the area of its application. Simulation can be used in many scientific fields from nature and human behaviour predictions, economics, to development of new technologies or safety engineering.

Generally, the simulation can be characterized as an imitation of a real-world process or system providing answers to “what if” scenarios. First, it requires a model with all crucial inputs and constraints to be developed. By running the simulation, you acquire the key characteristics and behaviours of the process or system over the time.

In process engineering, the simulation can be described as a mathematical tool to significantly reduce design time of specific plant or equipment offering multiple configurations to find optimal process conditions.

1.2 Simulation software - what is it and how it works

Nowadays there exist many simulation programs across various industries and disciplines which allow complex insight into complicated systems. Unlike physical modelling they offer highly economic, efficient and safe solutions based on mathematical algorithms and equations.

Main advantages they have in common are:

- Visualisation - easily understandable simulation models in 2D/3D
- Prediction of system behaviour beyond the range of usual operating conditions
- Risk-free opportunity to test “what-if” scenarios
- Major money and time savings

Process engineering simulation software is developed to design, analyse and optimise industrial plants based on solving mass and energy balances calculations to find a stable system operating point. Processes are defined by an excessive amount of linear, non-linear or differential equations which can be solved by different approaches - Sequential Modular, Equation Oriented or as a combination of both.

1.2.1 Sequential Modular (SM) Approach

In the SM approach (illustrative scheme in Figure 2), each unit operation model is represented by a module, that if given the input streams to the unit and relevant equipment specifications, solves the underlying model equations to determine the output streams and other Key Performance Indicators (KPIs) relating to design and operation of the unit. This method usually achieves a very high degree of robustness and efficiency within each individual module. [2]

The flowsheeting tool in the SM approach attempts to solve the overall flowsheet model by calling the individual unit operation modules in sequence. The simple “once-through calculation” is not possible in processes with recycles of material and/or energy. In such cases, the recycle streams need to be guessed (“torn”) and the flowsheeting tool calls the unit operations along the recycle to obtain new values of these recycles. This is repeated in an iterative manner until the values of these streams converge. It may take many iterations to converge even when starting from a reasonable set of recycle guesses. This problem typically becomes more acute in processes with multiple interacting recycles; and in some cases, the iterations may fail due to impropriate initial guesses. [2]

Another challenge for SM technology is the handling of non-standard specifications where it is desired to specify some aspect relating to the product streams or the overall process KPIs (e.g. overall raw material conversion), and to compute some aspects of equipment design or operation (e.g. reactor volume). This is problematic, since the required information flow is opposite to the fixed input-output structure of the individual modules. The common way of dealing with these specifications is via the introduction of artificial "controllers" that attempt to adjust automatically the values of the computed variables to match the user specifications. However, this introduces additional recycles of information that need to be handled in a manner similar to that described above for material and energy recycles. As a result, the use of SM technology for the calculation of plant optimisation has been somewhat limited in practice. [2]

Partly because of the perceived advantages in terms of robustness and usability, and partly because of the relative ease of its implementation, the SM approach has been the one adopted by most commercial steady-state flowsheeting tools, such as Aspen Plus® (Aspen Technology Inc.), Aspen HYSYS® (Aspen Technology Inc.), Petro-SIM® (KBC Advanced Technologies plc.), PRO/II® (Schneider Electric SimSci) and UniSim® (Honeywell Inc.). [2]

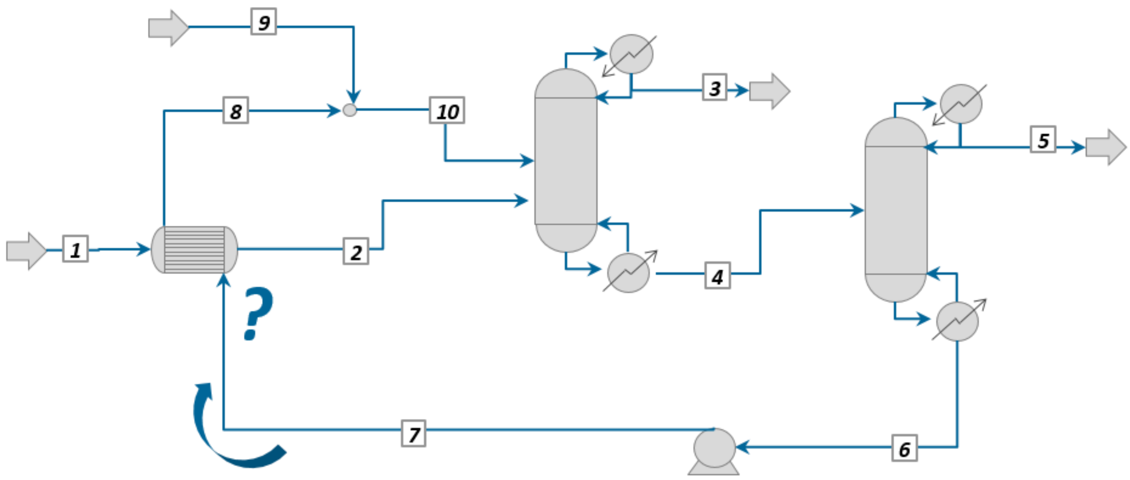


Figure 2: Sequential Modular Approach [3]

Advantages and disadvantages of Sequential Modular Approach are following [3]:

- \+ Easy to use and quick when it comes to simple calculations
- \+ Failure is rare, and clear diagnostics are issued
- \+ User interfaces and special solution methods can be hand-coded for each module
- – In-built directionality from inlets to outlets make 'downstream' specifications (e.g. product specs) difficult
- – Recycles may be (very) slow to converge, or fail to converge
- – Poor handling of multiple or complex recycles
- – Difficult to add new custom models; the user needs to code the solution method as well as model physics and chemistry
- – Optimisation capability is very limited
- – Many other limitations for more complex problems

1.2.2 Equation Oriented (EO) Approach

The EO approach (illustrative scheme in Figure 3) is conceptually much simpler than the SM one. When a mathematical model of each unit operation is created in the flowsheet in terms of a set of equations and variables, the overall plant model can be formulated simply by assembling the contributions of all unit operations, together with unit-unit connectivity relations, into one large system of equations. Once the user specifies a valid set of degrees of freedom, the latter is solved simultaneously via an appropriate numerical method. With modern algorithms and computer hardware, solution of systems of many hundreds of thousands of equations is feasible using ordinary desktop computers. [2]

In principle, EO technology can address many limitations of the SM approach described in the previous sections. For example, handling multiple interacting recycles is more efficient, since all relevant interactions are considered within the single system of equations. No special mechanisms are necessary for handling non-standard specifications if they also lead to square non-singular systems. [2]

The main limitation of EO technology has been the robustness of solution process. This is particularly important in the initial stages of modelling, when the values of the model variables are largely unknown, and any initial guesses may be far from the solution. Furthermore, given the size of the system of equations being solved, it is often difficult to locate the causes of a simulation failure, even when these are associated with errors in user specifications or user-provided models. The implementation of "industrial-strength" EO technology is technically much more challenging, mainly because of the underlying complexity of the software architecture and the mathematical solvers. [2]

Despite its more limited adoption, the potential advantages of EO technology are well understood and have led to the incorporation of some elements of EO technology within SM tools such as Aspen Plus where some of the unit operation models have both SM and EO modes, and custom models can be built as well using the Aspen Custom Modeler. However, the emergence of a "true" EO flowsheeting tool that can achieve the full potential afforded by the EO approach requires addressing the fundamental problem of model initialisation. [2]

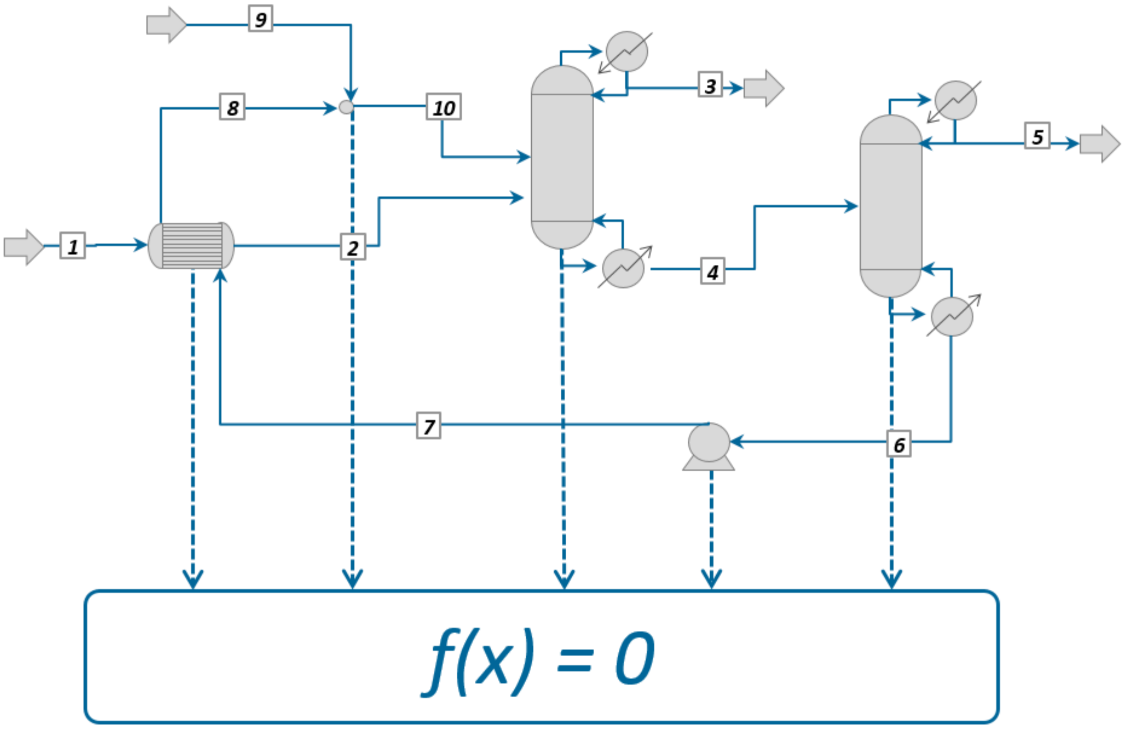


Figure 3: Equation Oriented Approach [3]

Advantages and disadvantages of Equation Oriented Approach are [3]:

+ No inherent directionality of computation - can be solved with any valid degree-of-freedom specification
+ Multiple recycles do not slow down convergence - they are simply treated as any other equation
+ Powerful optimisation, including integer decisions
+ Powerful custom modelling, with no need to program the mathematical solution
+ Repeat solution is much faster, making it possible to deploy large, complex models in demanding situations such as online real-time optimisation
– Numerical solvers may fail to find an initial solution unless good initial guesses are provided for all key variables
– It is often difficult to provide meaningful diagnostics on failure, making debugging difficult

1.2.3 Recent advances in EO Approach

Over the past decade, Process Systems Enterprise (PSE) has undertaken an extensive internal R&D programme aimed at addressing the robustness issues associated with the use of EO technology in the process flowsheeting context. This has resulted in the development of the novel concept of Model Initialisation Procedures (MIPs) operating at both the unit and the flowsheet levels. [2]

A unit-level MIP (UMIP) is simply a sequence of two or more models of a specific unit operation, such that (a) the first model in the sequence is one which is easy to solve even from poor initial guesses, and (b) the last model corresponds to the actual unit operation model. For example, for a complex non-adiabatic non-isothermal reactor model with axial and radial variations of temperature and composition, the U-MIP sequence could comprise 3 models of increasing complexity, e.g. (a) a model with no reaction taking place; (b) a model with reaction taking place at a specified temperature; and (c) the final reactor model with the full energy balance equations. In general terms, initialising the reactor model could be achieved by solving the three models in the order (a)→(b)→(c). See the illustrative scheme of MIP in Figure 4. U-MIPs are designed to ensure robust solution of any individual unit operation model. Flowsheet-level MIPs (F-MIPs) are essentially a set of mathematical algorithms for combining U-MIPs that allow a reliable and efficient convergence of entire flowsheets. [2]

By allowing robust solution of steady-state simulation calculations with little or no user intervention, MIPs represent a fundamental breakthrough in EO flowsheeting, addressing its main disadvantage in comparison with SM technology while retaining all of its inherent advantages, including handling flowsheets with multiple interacting recycles of material and energy, handling nonstandard specifications, and straightforward extendibility via fully integrated custom modelling. [2]

The consensus during this period has been that, whilst the EO approach is potentially much more powerful in terms of the scope of problems that could be addressed, only the SM approach was capable of providing the degree of robustness which is necessary to support wide deployment of these tools. However, recent technological developments in EO technology, especially in the area of model initialisation procedures but also in the enhanced usability of the software tools, are leading to significant changes in the relative balance between the two approaches. This opens the way for the power of EO flowsheeting to be made available to a much wider range of process industry users than has hitherto been possible. [2]

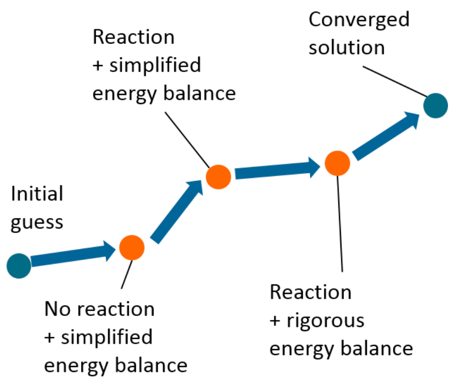


Figure 4: MIPs which help the unit to initialise [3]

1.3 Examples of process engineering simulation software

A short list of the few most well-known professional software in alphabetical order with basic general information is introduced in this subchapter.

1.3.1 Aspen HYSYS

Aspen HYSYS® (interface shown in Figure 5) is the industry leading simulation software for oil & gas, refining, and engineering processes. With an extensive array of unit operations, specialized work environments, and a robust solver, modelling in Aspen HYSYS enables user to [4]:

- Improve equipment design and performance
- Monitor safety and operational issues in the plant
- Optimize processing capacity and operating conditions
- Identify energy savings opportunities and reduce GHG emissions
- Perform economic evaluation to realize savings in the process design

1.3.2 Aspen Plus

Aspen Plus® (interface displayed in Figure 6) is the market-leading chemical optimization software used by the bulk, fine, specialty, and biochemical industries, as well as the polymer industry for the design, operation, and optimization of safe, profitable manufacturing facilities. With an extensive array of unit operations, several specialized work environments, and a robust solver, modelling in Aspen Plus enables users to [5]:

- Optimize processing capacity and operating conditions
- Ensure model accuracy with best-in-class physical properties
- Monitor safety and operational issues in the plant
- Identify energy savings opportunities and reduce GHG emissions
- Perform economic evaluation to realize savings in the process design
- Improve equipment design and performance

- Work more collaboratively with peers with tighter integration with adjacent products
- Reduce costs and improve product quality and throughput of process involving solids

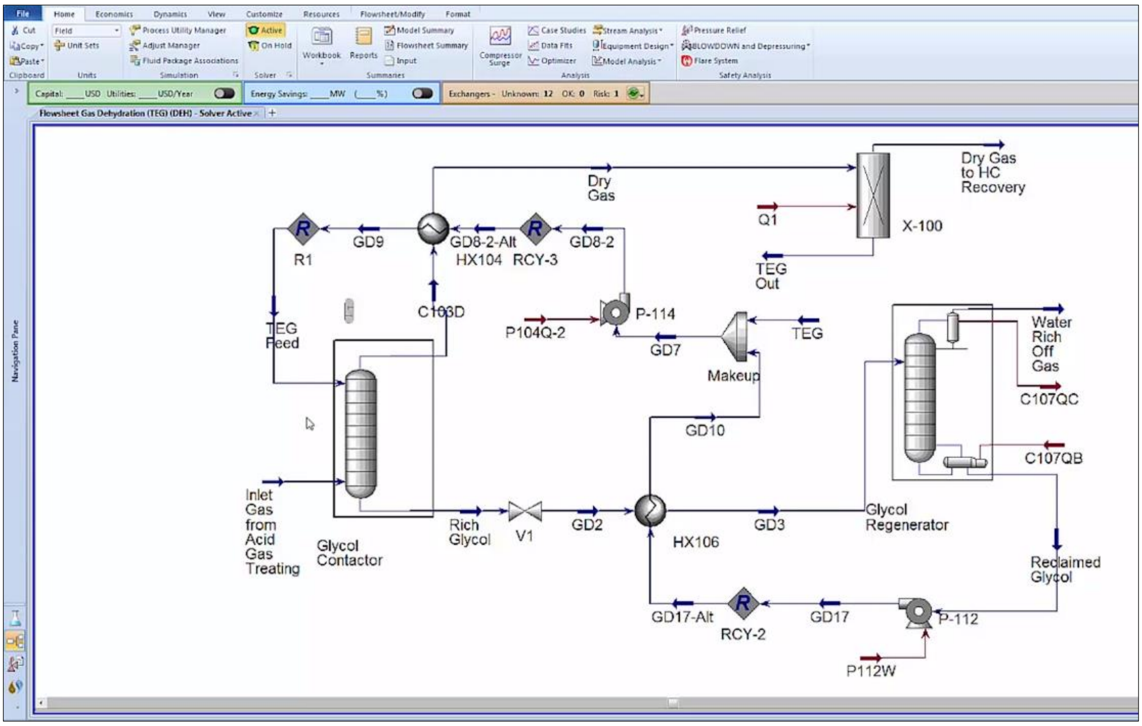


Figure 5: Example of Aspen HYSYS V9 interface [6]

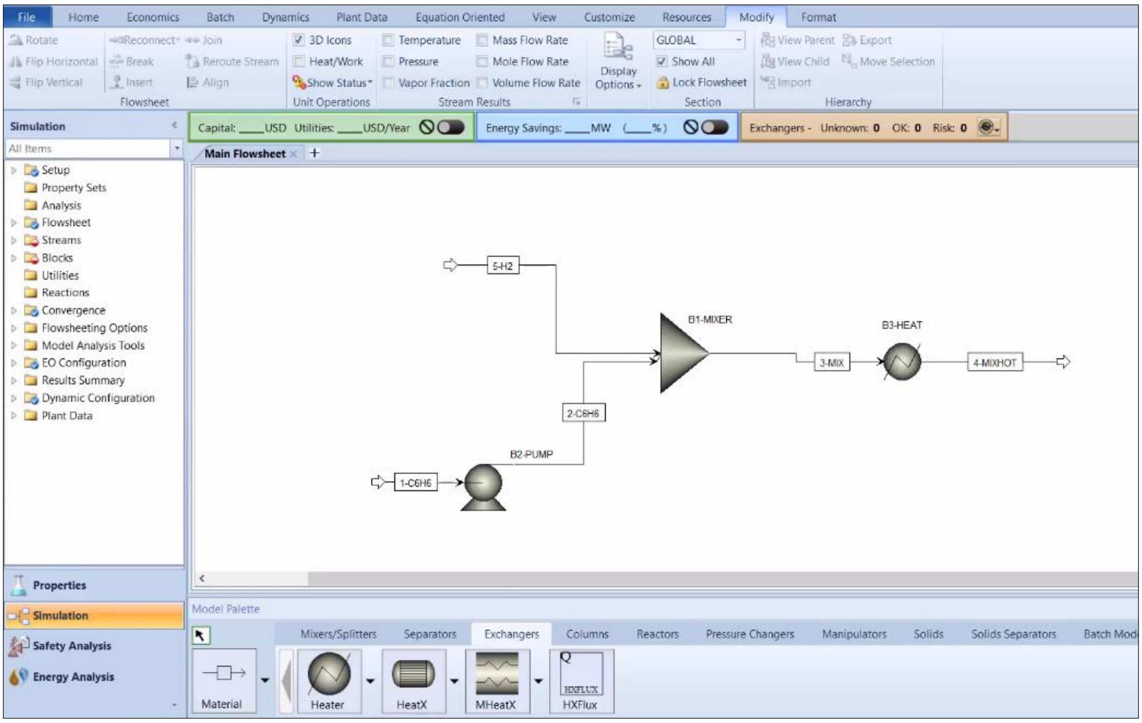


Figure 6: Example of Aspen Plus V10 interface [7]

Due to lack of experience of using Aspen software author of this thesis cannot describe major differences between Aspen Plus and Aspen HYSYS. Based on the internet reviews of long-term users, preference of one of the abovementioned softwares varies severely on a type of specific process and units you want to simulate. The biggest reason to choose one over the other seems to be existence/absence of prebuilt models and user-friendliness of their interfaces. However, both are very strong computational programs with significant amount of support and learning materials available on the internet.

1.3.3 CHEMCAD

CHEMCAD (example of interface in Figure 7) is a powerful and flexible chemical process simulation environment, built around three key values of innovation, integration, and open architecture. These values create important advantages for CHEMCAD users [8]:

- The latest chemical engineering techniques at your fingertips
- All functionality united in a single software environment
- Seamless connection to the chemical engineering computing environment, with links to tools such as MS Excel and Word and interfaces such as COM, DCOM, OPC, CAPE-OPEN, and XML

CHEMCAD is capable of modelling continuous, batch, and semi-batch processes, and it can simulate both steady-state and dynamic systems. This program is used extensively around the world for the design, operation, and maintenance of chemical processes in a wide variety of industries, including oil and gas exploration, production, and refining; gas processing; commodity and specialty chemicals; pharmaceuticals; biofuels; and process equipment manufacturing. [8]

The CHEMCAD suite consists of several modules that serve specific purposes [8]:

- CC-STEADY STATE enables you to design new processes, rate existing processes, and optimize processes in steady state
- CC-DYNAMICS makes it possible to design new and rate existing processes using a dynamic simulation
- CC-BATCH enables you to design, rate, or optimize a batch distillation column
- CC-THERM lets you design a single heat exchanger, or vet a vendor’s heat exchanger design
- CC-SAFETY NET provides the capability to design or rate piping networks and safety relief devices and systems, in both steady-state and dynamic systems
- CC-FLASH provides physical property and phase equilibrium data, as well as property prediction and regression

From thesis author’s point of view, CHEMCAD is a very intuitive, user-friendly and easy-to-learn software offering a lot of useful flexible tools and functions. It seems to be broadly spread across academic and industrial sphere as well, providing excessive learning materials.

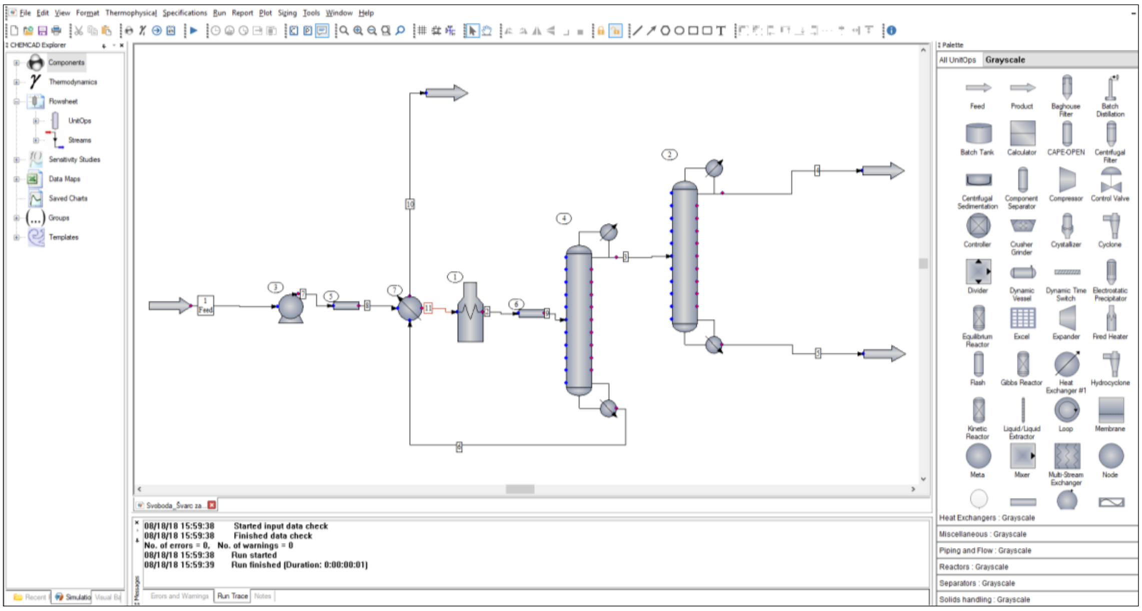


Figure 7: Example of CHEMCAD 7 interface [8]

1.3.4 PRO/II Process Engineering

PRO/II Process Engineering (interface demonstrated in Figure 8) optimizes plant performance by improving process design and operational analysis and performing engineering studies. It is designed to perform rigorous heat and material balance calculations for a wide range of steady-state chemical processes. Key features [9]:

- Comprehensive thermodynamics, physical property data and unit operation modelling
- Creation and management of custom component data
- Customizable process modelling via Microsoft® Excel
- Built-in integration with Excel for custom reporting
- SIM4ME® Portal integration for simulation control and analysis from Excel
- Integration with industry-standard licensors including HTRI, OLI & Koch-Glitsch
- Integration with Spiral CrudeSuite for assay information
- Application across multiple industries such as Green Engineering, Chemicals, Refining, Polymers, Oil & Gas Processing, Pharmaceuticals and Petrochemicals
- PRO/II Process Engineering is available via the cloud in addition to the traditional on-premise access method

1.3.5 ProMax 4.0

ProMax (interface presented in Figure 9) is a flexible, stream-based process simulation package used for the design and optimization of gas processing, refining, and chemical facilities. ProMax provides flexibility to its users through access to over 65 predefined thermodynamic package combinations and over 3200 components, along with crude oil characterization and compound species capabilities. For unit operations, the user has access to pipelines, fluid drivers (compressors and pumps), heat exchangers, vessels, distillation columns, reactors, membranes, and valves. In addition, ProMax provides OLE automation tie-ins, specifiers, solvers, and Microsoft Excel® spreadsheet embedding, which give the user full access and control of all the information within any stream or block. The ProMax interface is built around the Microsoft Visio® package. Therefore, it inherits many of the benefits of this package (e.g., shape sizing, transformation, text annotations, etc.). [11]

Thesis author's opinion is that ProMax software is user-friendly and easy-to-use. Developing company Bryan Research & Engineering offers free training courses.

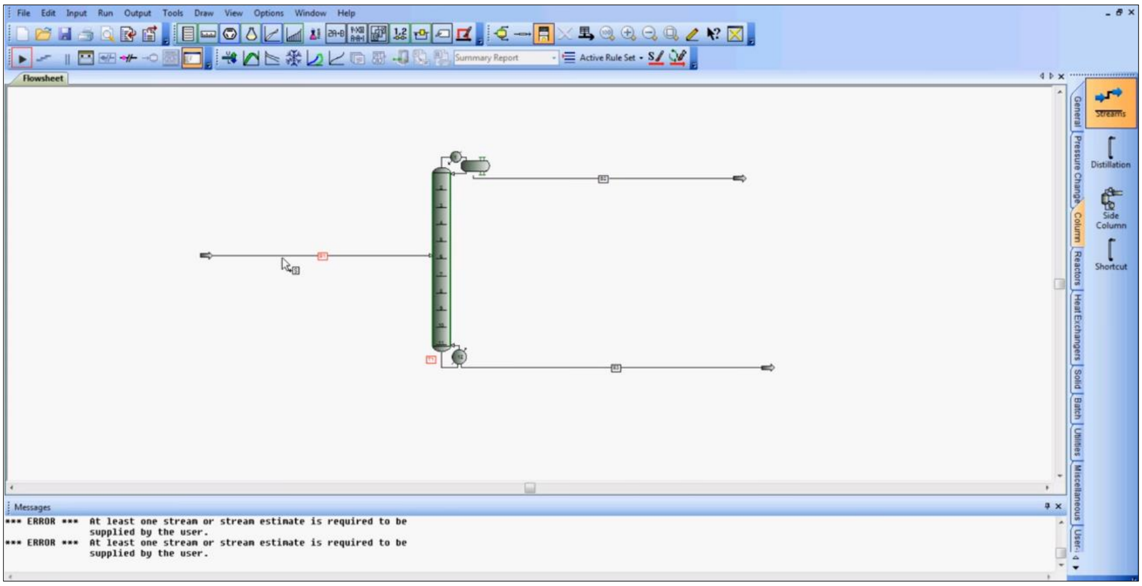


Figure 8: Example of PRO/II interface [10]

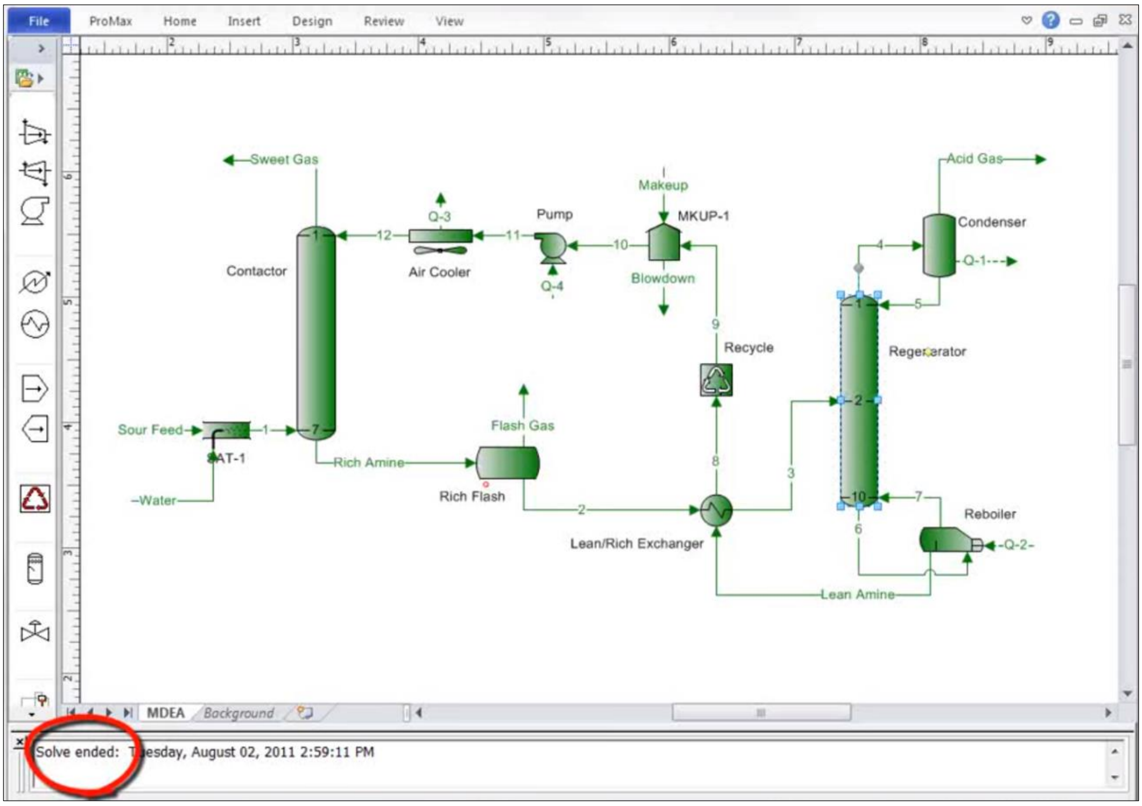


Figure 9: Example of ProMax 4.0 interface [12]

2 GateCycle simulation software

The main part of this thesis is a study and practical application of GateCycle software for specific process and power-plant systems simulation. In this chapter a workspace of GateCycle is presented together with quick instructions how to create and run a simulation. Illustrational simulation report analysis is introduced, along with predefined GateCycle model library at the end of the chapter.

2.1 Gate Cycle introduction

The GateCycle program is a PC-based software application that performs detailed, steady-state design and off-design analyses of thermal power systems. GateCycle can perform a large variety of analyses, such as [13]:

- Designing and analysing an overall cycle for a proposed power system or cogeneration station (this analysis produces information on operating performance at all the statepoints throughout the station, including overall cycle efficiency and power)
- Checking claims made by vendors about the performance of entire power plants or individual hardware
- Simulating the performance of existing systems at “off-design” operating conditions.
- Predicting the effect of proposed changes or enhancements to existing plants
- Analysing advanced gas turbine designs, including designs that are fully integrated with the steam/water cycle

2.2 Model vs. Cases

A GateCycle model consists of a single, physical layout (model diagram) of a thermal power system created by the user. The GateCycle model diagram is also referred to as a *flowsheet* or a *process flow diagram* (PFD). Each model has at least one case, the *reference case*, which defines all the equipment layout and connection information for that model. In GateCycle it always has the same ID as the model itself. Besides the reference case, there can be an unlimited number of associated cases to the same model diagram or flowsheet. Hence, the data in each case must be structured in the same way, but each case can be thought of as an independent set of inputs and results for that model. Demonstrative scheme is shown in Figure 10. [13]

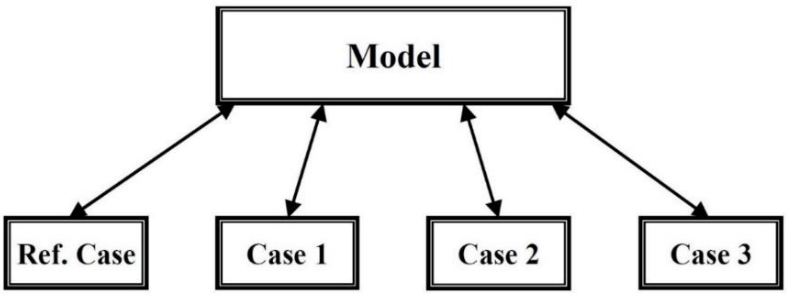


Figure 10: Model vs. Cases [13]

2.3 Design vs. Off-Design

By default, the reference case of a GateCycle model is used to design each piece of equipment, represented by an icon on the model diagram. Any case of any model, however, can be used as the design basis of a GateCycle equipment icon. A design-mode run for any GateCycle icon calculates the physical size (and other design parameters) from key specified performance parameter (e.g. the required heat exchanger surface area to raise a fluid to a specified temperature). Once a design case has been created for an equipment icon, this case can be referenced by the same icon running in off-design mode in another case (either within the same model or a different model). This enables the user to analyse the performance of a "physically-based" equipment icon (e.g. fixed surface area heat exchanger) under off-design operating conditions. [13]

You may choose to mix design and off-design equipment icons in a single case to test the effects of plant hardware additions and perform repowering studies. A common practice is to set up a design case for a heat recovery steam generator (HRSG) that includes an off-design steam turbine. This allows you to use a modular approach to system design, where the steam turbine is isolated in a separate model for detailed design before being implemented in the actual steam cycle. [13]

2.4 GateCycle Interface

After starting GateCycle you will see an initial launch screen shown in Figure 12. Descriptions of individual panes are divided in the following subchapters.

2.4.1 Workspace

Workspace is the biggest white area in the centre of the screen. It is the place where you drag and drop particular equipment icons and by connecting them with specific streams you obtain a flowsheet of the simulated process. When opening multiple models or cases you can switch between them by using tabs that are displayed in the upper part of the workspace.

2.4.2 Model and Case Explorer

Model explorer (Figure 11) helps you to navigate in the database of all saved GateCycle models and cases. It also shows the quick description whether it is Design or Off-design Case.

Case explorer reveals a list of all equipment and streams implied in specific case.

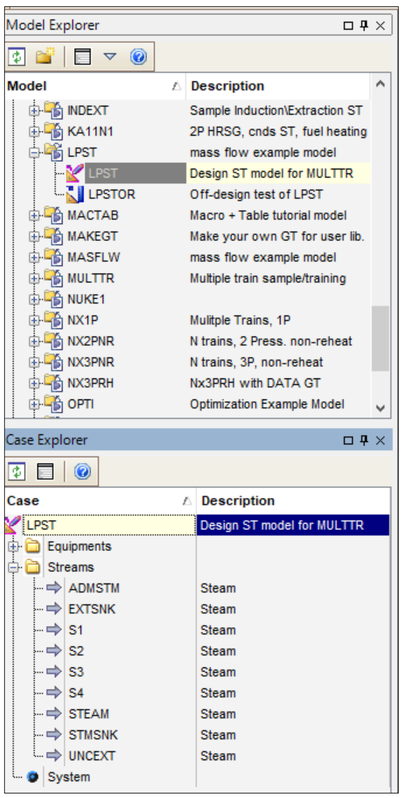


Figure 11: Model and Case explorer

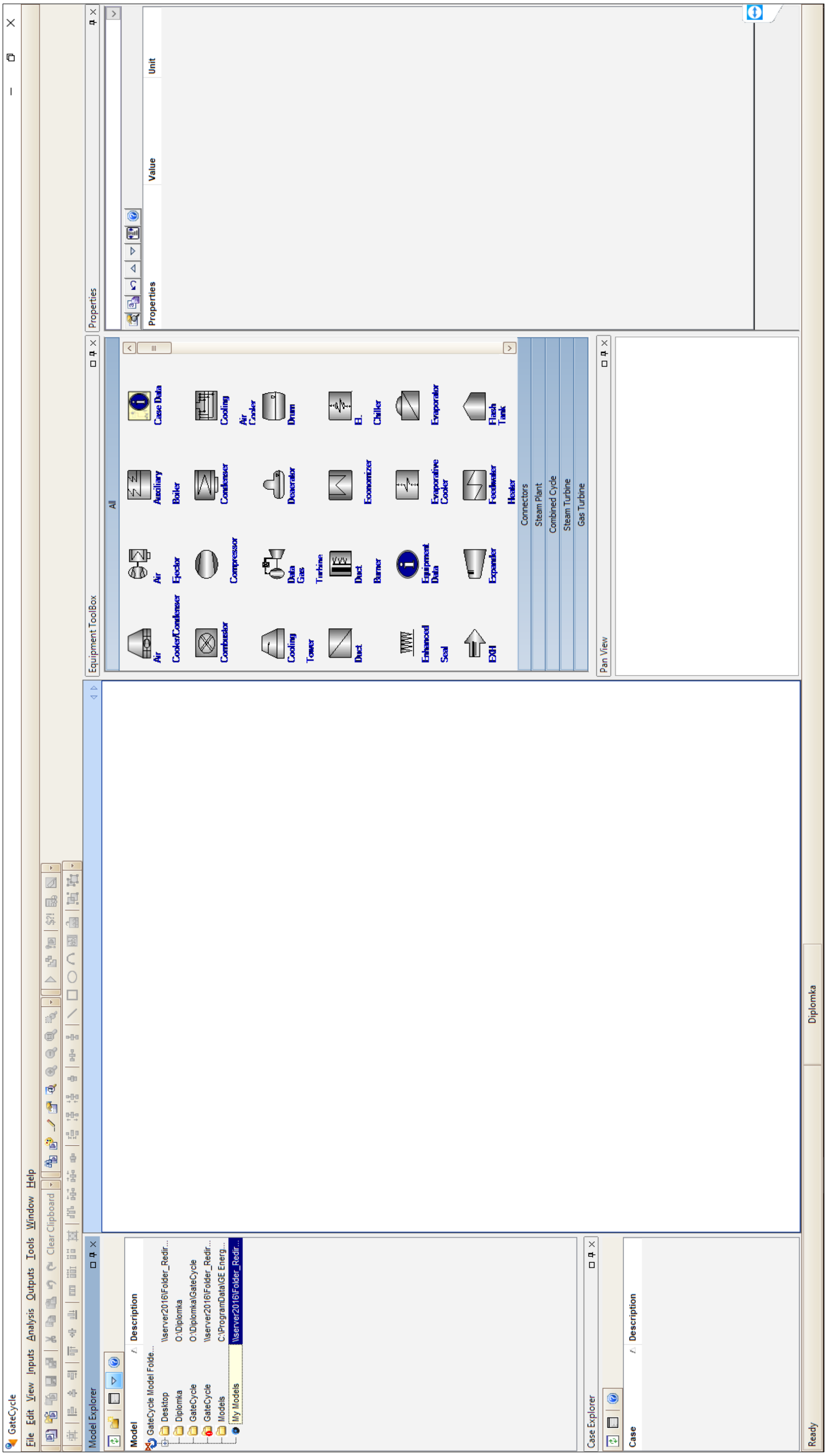


Figure 12: GateCycle launch screen

2.4.3 Equipment Toolbox

Equipment toolbox displays all available equipment and data icons sorted in categories by the alphabetical order. After dropping equipment icon to workspace and pressing F1, program shows explicit unit description. A quick overview of the unit and connection possibilities are shown, together with the information about pressure and flow signals, followed by details about calculation methods, initialization values and calculated results.

GateCycle assigns a default ID to each equipment icon which can be easily changed after double-clicking on it. Resizing and other graphic adjustments of icons are certainty. Many other options can be set up via button "*Tools → Options → Settings*".

2.4.4 Properties Pane

The purpose of Properties Pane is to input data to specific unit or stream as well as to review calculated results and flows, see the Figure 13. GateCycle uses "guided data entry" approach to help you supply the minimum required information to your model. It means that the most of equipment already has some predefined input values. On the one hand, it helps you to quickly set up and run your simulation. On the other hand, it is necessary to get familiar with all input default values and its influence on your model. For further understanding it is highly recommended to examine related topics and input and output data of utilized equipment icons in program help.

To see all necessary data to input, click "*Analysis → Build Review*" (shortcut F7). You can easily determine which equipment needs your attention by seeing following symbols in Properties pane:

This property contains all default values and no further information is being required.

This property contains at least one user-modified value and no further information is being required.

Information is invalid or missing for this property.

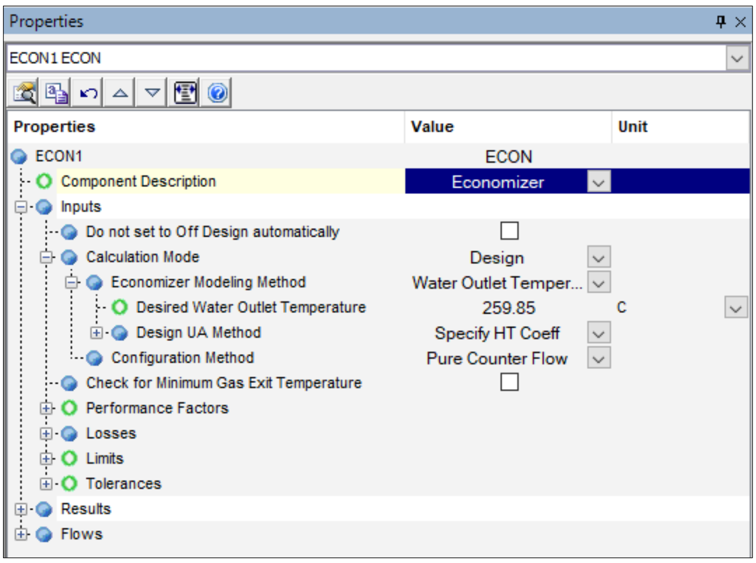


Figure 13: Properties Pane

2.4.5 Pan View Frame

This window eases the orientation in the flowsheet of simulated model. It shows which part of the model is currently zoomed. Workspace may be zoomed to the level of particular unit icons while Pan View frame serves to ease movement across whole flowsheet. See the illustrative example in Figure 14.

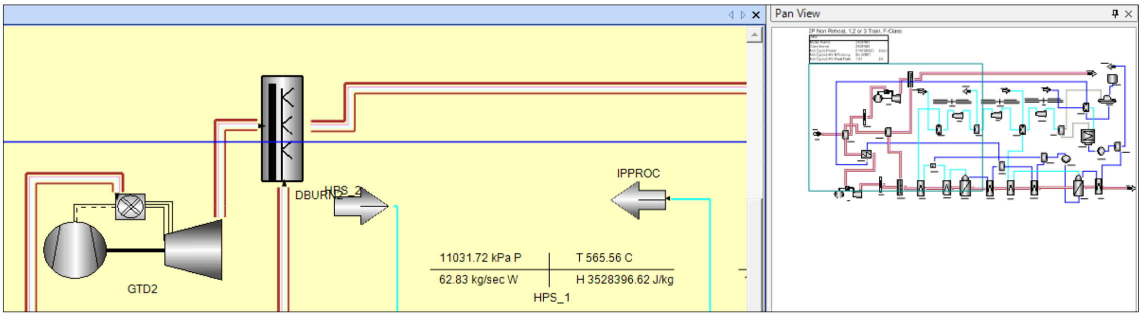


Figure 14: Pan View Frame

2.5 Building, running and analysing a new simulation

GateCycle basic interface was already swiftly introduced. More detailed information about setting, running and analysing the simulation is presented in this subchapter. The simple model illustrated in Figure 15 is used for demonstrative purposes.

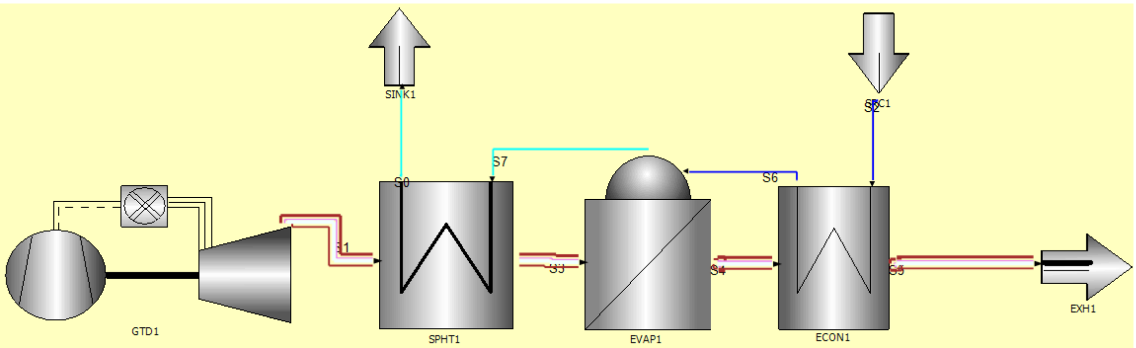


Figure 15: Demonstrative example of simple HRSG model

2.5.1 Building a new model

To begin a new process simulation, simply click on "*File → New Model*" (shortcut Ctrl + N). A blank drawing area appears. You can modify your interface by clicking on "*View*" and setting which windows mentioned in previous subchapter you want to have displayed.

Open Equipment Toolbox window and drag and drop equipment icons to workspace according to Figure 15. To be specific, following units are used - *Data Gas Turbine, Superheater, Evaporator, Economizer, Exhaust, Source* and *Sink*. After clicking on the unit, individual ports for both water and exhaust gas path reveal. If you place a cursor over the port, description of the port will appear as a pop-up. See the situation in the Figure 16.

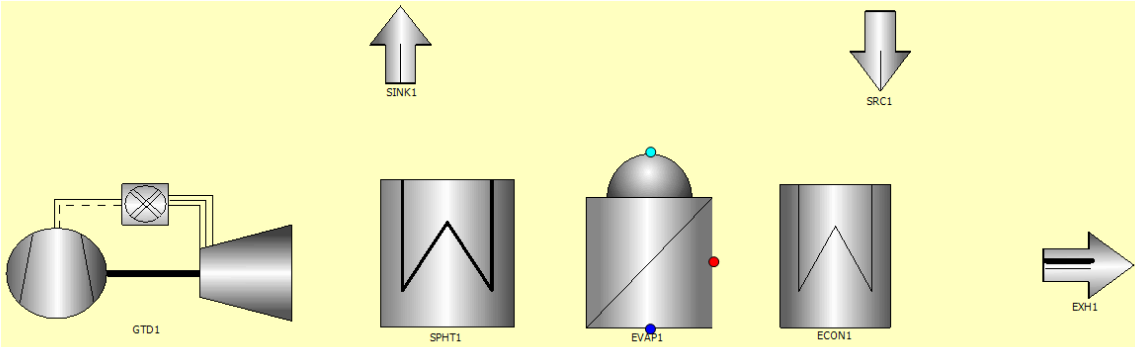


Figure 16: Simple HRSG model without streams

Next step is adding stream connections. Start with the gas turbine and consequently connect exhaust gas stream to other HRSG units, ending with a gas sink (*Exhaust* icon). Do the same with water / steam stream from *Source*, through HRSG heat exchangers up to *Sink* icon. Notice the different colours, red for gas and fuel, blue for water and turquoise for steam stream. Now your model should look like the one in the Figure 15.

2.5.2 Data supplying

The first thing in data inputting procedure is selection of proper engineering units. Click on "*Tools → Unit Set Editor*" and choose one of predefined sets. You can create your own preferred unit set, see the Figure 17. It is a general setting, therefore you can use it in all other models as well. To change a unit in one specific equipment, double-click on it and do so in the Property frame.

To proceed with simulation building, double-click on empty workspace area and general system property frame appears (Figure 18). You can choose between various methods and formulas to calculate steam, salt water and real gas properties.

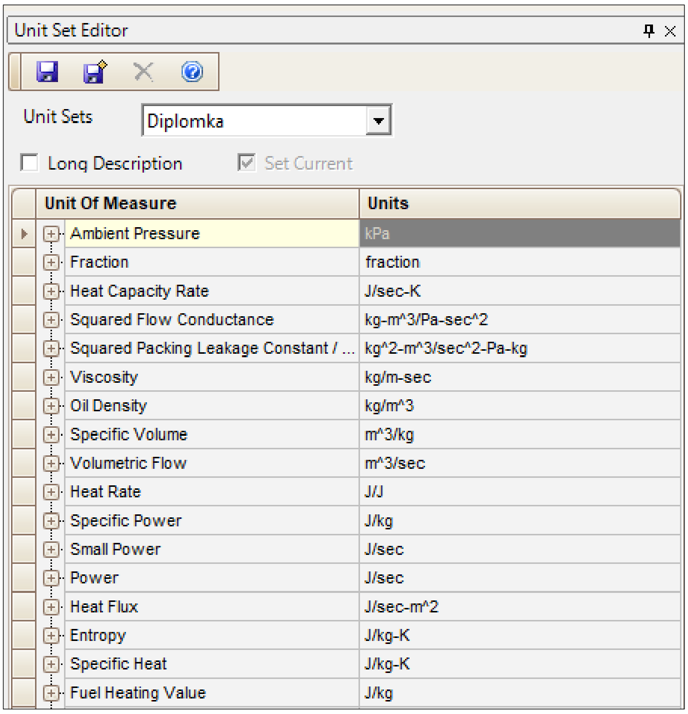


Figure 17: Unit Set Editor

It is important to define system gas (for instance by its molar or mass composition and GateCycle calculates its heating value, either lower or higher) and ambient environment as well (temperature, pressure, humidity). You can establish amount of iterations, tolerances limitations and other system properties, as well.

Now is the time to supply input data into all of the equipment. Since the model is only illustrative and its purpose is to show the simulation building and report analysing procedure, there are no exact equipment input data specified in this chapter. Thoroughgoing step-by-step guide how to make a simulation of industrial steam boiler with concrete data will be shown in Chapter 3.

General recommendation for data supplying is to follow the instructions from subchapter 2.4.4 and check which values were predefined, whether it is a reasonable guess and which ones need to be user-modified.

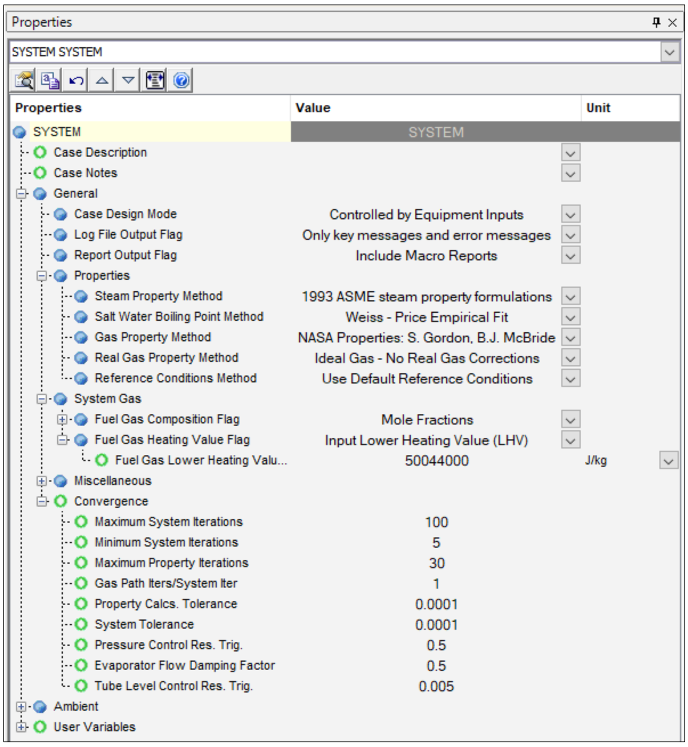


Figure 18: System properties

A very important concept to bear in mind during the whole simulating process is mass balancing. Total flow leaving the system through sinks, deaerator vents, etc. must be in balance with flow entering the system. For this purpose, you may use either Source icon (specifies a fixed mass flow of water or steam) or Makeup block (balances the mass flow automatically, can be linked to return the flow leaving from up to four sinks).

During the construction of a new model, one must be careful with the connection of equipment icons to set up mass flow calculations which function properly. Evaporators, boilers and drum icons generally determine the total mass flow through the system in GateCycle.

Usually, the data generated in particular equipment are passed downstream to the outlet ports connected icons. However, there are some exceptions. A few equipment icons demand the incoming mass flow by controlling the settings of upstream icons. GateCycle sequentially passes information upstream until it finds downstream-flow-controllable port (for instance a splitter outlet or stream extraction port). For further tips you can learn more in “*Running GateCycle Analysis - Mass Balancing*” and “*Running GateCycle Analysis - Mass Flow Control Examples*” sections in program Help (shortcut F1).

2.5.3 Running a simulation

In the previous subchapter, a simple demonstrative model was built. Now, to run a simulation simply click on "*Analysis → Run Cycle*" (shortcut F4) and dialog box shown in Figure 19 appears to display the model execution status.

Using the *"Pause"* or *"Cancel"* buttons the calculations during the run can be interrupted (for example if any errors or warnings are presented).

By monitoring convergence residual and number of iterations a convergence problem can be determined. Colour differentiation helps to identify warnings (yellow) and errors (red). Once the model has converged, net cycle power and its efficiency is displayed in this window.

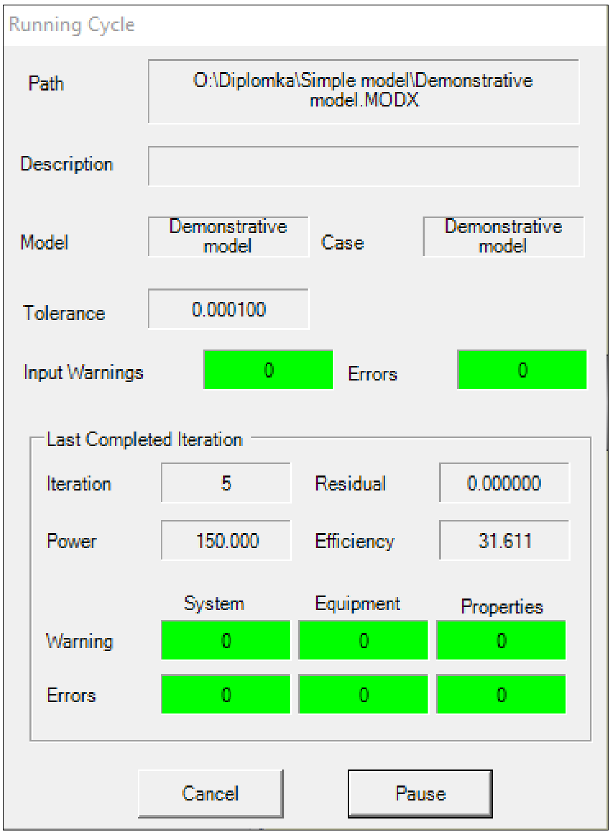


Figure 19: Running Cycle

At the same time, another dialog box (Figure 20) pops up, asking whether you would like to save the simulation results or not. When the imulation run starts, GateCycle takes the values presently stored in the database from last simulation and uses them as initial guesses for the iterative calculations.

Mostly, this is the best array of initial values to obtain the fastest model convergence. Despite that, in case of serious errors in previous simulation run, results stored in database may be so far off that they could cause the simulation run to not converge. In this occasional situation, the only option to fix your model is to replace actual inconvenient values with good ones. They can be either copied from another case or entered manually into equipment Property window. In case of reported errors in the *"Running Cycle"* dialog box, not saving the results is a good practice. Instead, you should fix your model by reviewing the cycle Error file shown in Figure 21. You can display it by clicking on "*Analysis → Show Error File*" (shortcut Ctrl+E).

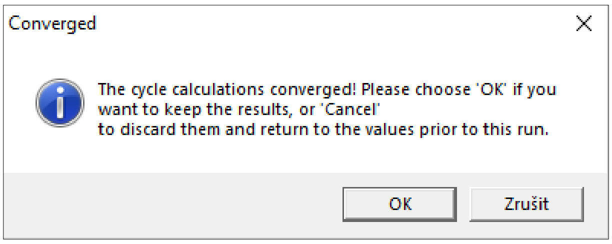
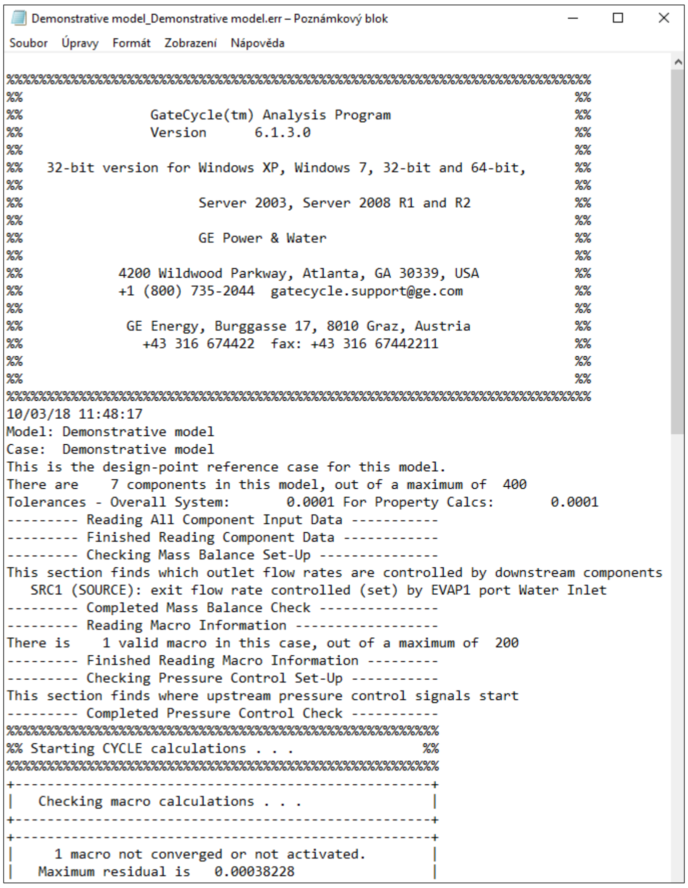


Figure 20: Notification of convergence

During the simulation, GateCycle makes a record of every step of the cycle run in text files. If any warnings or errors are indicated after the model convergence, they will be published in *"cycle.err"* file which you can consequently use to debug your model. It is recommended to first review the information at the beginning of the file, to see the potential fails through the model setup and data input checking phase. To proceed, scroll down to the end of the file to check for possible errors and warnings throughout the final iteration. It is useless to search for any warnings during previous iterations because they may disappear as the iteration progressed.

GateCycle records the abovementioned information to the Log file (*"cycle.log"*) as well. The difference is that Log File lists a configurable number of messages from the last cycle analysis. If the debug messaging level is set to the lowest, the composition is the same as for the Error file. Sometimes the Error file output does not provide sufficient amount of data to determine the source of analysis errors.

You can configure the volume of information provided in Log file in System Properties window, see the Figure 22. To acquire extensive insight into this problematic, examine *"System Input - Debug Output Control"* and *"Debugging Models"* sections in Help.



Demonstrative model_Demonstrative model.err – Poznámkový blok
Soubor Úpravy Formát Zobrazení Nápověda

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%                                                                      %%
%%                 GateCycle(tm) Analysis Program                       %%
%%                 Version      6.1.3.0                                 %%
%%                                                                      %%
%%     32-bit version for Windows XP, Windows 7, 32-bit and 64-bit,     %%
%%                                                                      %%
%%                  Server 2003, Server 2008 R1 and R2                  %%
%%                                                                      %%
%%                          GE Power & Water                            %%
%%                                                                      %%
%%            4200 Wildwood Parkway, Atlanta, GA 30339, USA             %%
%%            +1 (800) 735-2044  gatecycle.support@ge.com               %%
%%                                                                      %%
%%             GE Energy, Burggasse 17, 8010 Graz, Austria              %%
%%               +43 316 674422  fax: +43 316 67442211                  %%
%%                                                                      %%
%%                                                                      %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
10/03/18 11:48:17
Model: Demonstrative model
Case:  Demonstrative model
This is the design-point reference case for this model.
There are    7 components in this model, out of a maximum of  400
Tolerances - Overall System:       0.0001 For Property Calcs:       0.0001
--------- Reading All Component Input Data -----------
--------- Finished Reading Component Data ------------
--------- Checking Mass Balance Set-Up ---------------
This section finds which outlet flow rates are controlled by downstream components
   SRC1 (SOURCE): exit flow rate controlled (set) by EVAP1 port Water Inlet
--------- Completed Mass Balance Check ---------------
--------- Reading Macro Information ------------------
There is    1 valid macro in this case, out of a maximum of  200
--------- Finished Reading Macro Information ---------
--------- Checking Pressure Control Set-Up -----------
This section finds where upstream pressure control signals start
--------- Completed Pressure Control Check -----------
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Starting CYCLE calculations . . .              %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
+-----------------------------------------------------+
|   Checking macro calculations . . .                 |
+-----------------------------------------------------+
+-----------------------------------------------------+
|     1 macro not converged or not activated.         |
|   Maximum residual is    0.00038228                 |
```

Figure 21: Cycle Error file

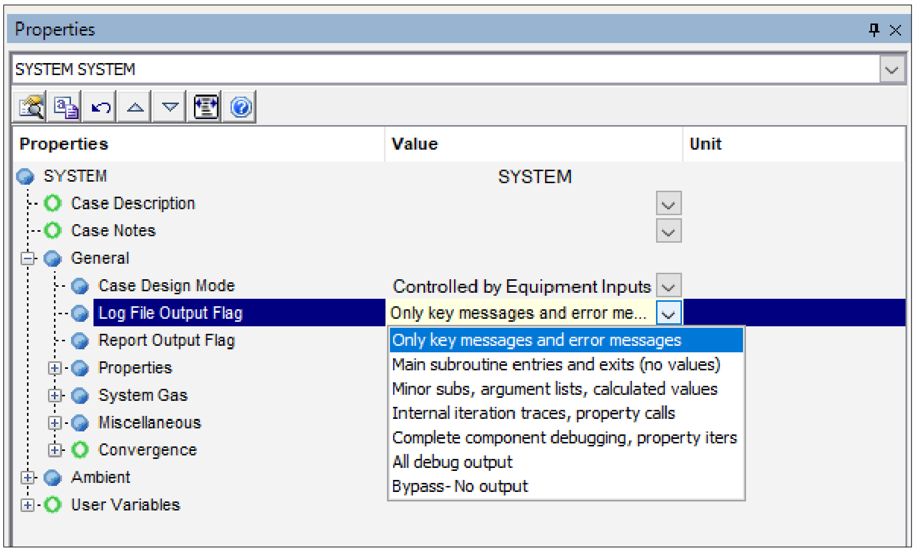


Figure 22: Log file output configuration

2.5.4 Results Analysis

In this subchapter, multiple options how to view and print results of your model are being introduced. Generally, there are three categories of output data in GateCycle. Namely, specific piece of equipment data, whole-cycle-associated data and graphical output.

To display data related to the piece of equipment after the simulation run, right click on its icon (or stream label for Sources and Sinks, respectively) and click on the "*Report*" button. Subsequently, a report shown in Figure 23 appears.

GateCycle Report	SPHT1 Report
Model :**Demonstrative model** Case :**Demonstrative model**	10/03/2018 12:36:32
Prepared using GateCycle Version	6.1.3.0
Date and Time of Last Run	10/03/18 12:06
Last Execution Status	Converged

Equipment ID :SPHT1 Type :SPHT Description :Superheater Go to Top

		Gas Inlet	Gas Outlet	Steam Inlet	Steam Outlet
Flows	kg/hr	1508400.0112	1508400.0112	287889.9663	287889.9663
Pressure	kPa	101.32	101.32	172.3689	172.3689
Temperature	C	587.0001	512.7965	115.5952	375.0003
Enthalpy	kJ/kg	718.5722	617.1897	2699.6013	3225.5362
Vapor Fraction on a weight basis	fraction			1	1
Molecular Weight		27.1802	27.1802		
Lower Heating Value	kJ/kg	0	0		
Oxygen, O2	fraction	0	0		
Nitrogen, N2	fraction	0.6596	0.6596		
Water, H2O	fraction	0.1794	0.1794		
Carbon Monoxide, CO	fraction	0	0		
Carbon Dioxide, CO2	fraction	0.0923	0.0923		
Methane, CH4	fraction	0.0542	0.0542		
Hydrogen, H2	fraction	0	0		
Argon, AR	fraction	0.0079	0.0079		
Carbonyl Sulfide, COS	fraction	0	0		
Hydrogen Sulfide, H2S	fraction	0	0		
Sulfur Dioxide, SO2	fraction	0	0		
Ethane, C2H6	fraction	0.0049	0.0049		
Propane, C3H8	fraction	0.0018	0.0018		

Main Inputs

Calculation Mode	Design	
Superheater Method Flag	Steam Outlet Temperature	
Desired Steam Outlet Temperature		375 C
Steam Outlet Temperature		375.0003 C
Design UA Method	Specify Heat Transfer Coefficient	
Overall Heat Transfer Coefficient		0.0454 kJ/sec-m^2-K
Configuration Method	Cross-Counter-Current, 1 Tube Row per Pass, Inner Flow Mixed, Outer Unmixed	
Number of HTX Passes		10

Figure 23: Equipment Report

To view overall cycle data, simply click on *"Outputs → Case Report"* (shown in Figure 24) and choose specific form of report. Basically, they differ in volume of information provided and their format and they are all introduced below.

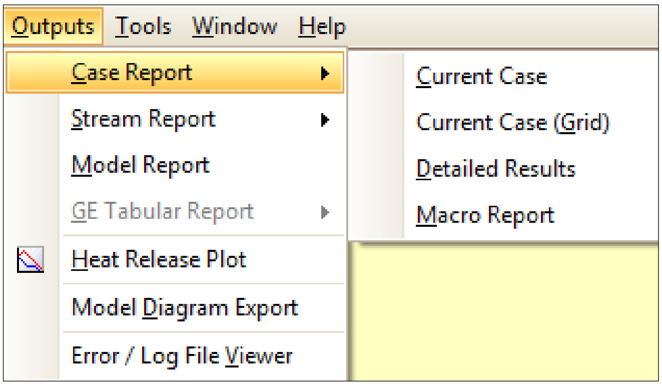


Figure 24: Report options

After clicking on *"Current Case"* button, GateCycle shows an overall case summary in html format which contains only basic information. You can see illustrative Current Case Report in Figure 25.

Option *"Current Case (Grid)"* offers summary of these data in a transparent grid format (Figure 26) which can be simply copied into Excel file. Choose *"Detailed Case Report"* to obtain an in-depth detailed report with all inputs and results. You can create the report with an optional amount of information by ticking various boxes, see the Figure 27.

GateCycle Report	SYSTEM Report
Model :**Demonstrative model**	10/03/2018 12:32:12
Case :**Demonstrative model**	
Prepared using GateCycle Version	6.1.3.0
Date and Time of Last Run	10/03/18 12:06
Last Execution Status	Converged

Overall System Results

Model ID	Demonstrative model
Case ID	Demonstrative model
Case Description	
Case Notes	

Program Execution Data

Execution Status	Converged	
Execution Time	00:00:01	
Iterations Used		5
Final Iteration Residual		0
Final Iteration Warnings		0
Final Iteration Errors		0
System Tolerance		0.0001
Property Calcs. Tolerance		0.0001
Number of Active Macros Used		1
Maximum Macro Residual		0.0004

Main Inputs

Case Description

Case Notes

General

Case Design Mode	Controlled by Equipment Inputs
Log File Output Flag	Only key messages and error messages
Report Output Flag	Include Macro Reports

Properties

Steam Property Method	1993 ASME steam property formulations
Salt Water Boiling Point Method	Weiss - Price Empirical Fit
Gas Property Method	NASA Properties: S. Gordon, B.J. McBride
Real Gas Property Method	Ideal Gas - No Real Gas Corrections
Reference Conditions Method	Use Default Reference Conditions

Figure 25: Current Case Report

Case Report - Model :Demonstrative model

Variable	Demonstrative model	Unit
Ambient Temperature	15	C
Ambient Pressure	101.32	kPa
Ambient Relative Humidity	0.6	
Ambient Specific Humidity	0.0063	
Equivalent Elevation	0.449	m
Net Cycle Power	150000	kW
Net Cycle Lower Heating Value (LHV) Efficiency	7.7798	
Net Cycle Lower Heating Value (LHV) Heat Rate	12.8534	kJ/kW-sec
Net Gas Turbine Power	150000	kW
GT Shaft Power	152284.3	kW
GT Generator Losses	2284.256	kW
GT Auxiliary and BOP Losses	0	kW
GT Simple-Cycle Lower Heating Value (LHV) Efficiency	7.7798	
Total Lower Heating Value (LHV) Fuel Cons.	1928003	kJ/sec
Net Steam Cycle Power	0	kW
ST Shaft Power	0	kW
ST Generator Losses	0	kW
Steam Cycle BOP Losses	0	kW
ST Generator Output	0	kW
Credit for Equivalent Fuel	0	kJ/sec
Credit for Equivalent Power	0	kW
Adjusted Cycle Lower Heating Value (LHV) Efficiency	7.7798	
Adj. Cycle Lower Heating Value (LHV) Heat Rate	12.8534	kJ/kW-sec

Figure 26: Current Case (Grid) Report

Click on *"Outputs → Stream Report"* generates a table of all streams in current GateCycle model diagram and presents their thermodynamic properties such as flow rates, temperature, pressure etc. See the example of Stream Report in Figure 28. *"Macro Report"* lists all the macros used in the model.

Differently from "*Case Report*", option *"Outputs → Model Report"* includes key system results in column-by-column listing (in the grid case report format) of all cases in the ongoing model. It helps for a quick summarization and comparison of your cases.

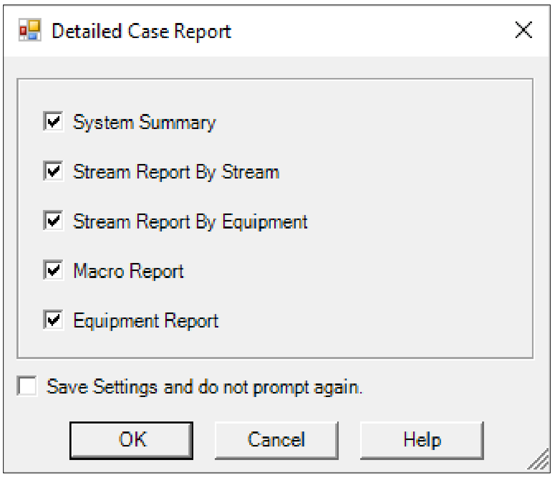


Figure 27: Detailed Case Report

As in many other simulation programmes, results can be viewed and exported in graphical format as well. To acquire basic stream data displayed in workspace, as seen in Figure 29, right click on any stream and select "*Show All → Data Component*". Subsequently right click on stream which result you want to see and click on *"Add Data Component"*.

You can generate a temperature profile plot of your HRSG operating data using the command "*Outputs → Heat Release Plots*". Example of such a graph is shown in Figure 30. To print any of the abovementioned reports, right click on the report and choose "*Print*" option.

GateCycle Report	Stream Report
Model :Demonstrative model	10/03/2018 12:28:14
Case :Demonstrative model	
Prepared using GateCycle Version	6.1.3.0
Date and Time of Last Run	10/03/18 12:06
Last Execution Status	Converged

Stream Report Go to Top

Stream	From	To	Flow	Pressure	Temperature	Enthalpy	Quality
			kg/hr	kPa	C	kJ/kg	
Primary Fuel Inlet	GTD1	GTD1	146274.3765	2068.4298	26.67	22.9493	1
Inlet Air	GTD1	GTD1	1362125.663	101.32	15	-0.561	1
Blowdown Outlet	EVAP1	EVAP1	0	172.3689	115.5952	485.023	0
S0	GTD1	SPHT1	1508400.0112	101.32	587.0001	718.5722	1
S1	SPHT1	EVAP1	1508400.0112	101.32	512.7965	617.1897	0
S2	EVAP1	ECON1	1508400.0112	101.32	126.5952	128.9594	0
S3	ECON1	EXH1	1508400.0112	101.32	110	109.4099	0
S4	SRC1	ECON1	287889.9663	172.3689	15.5556	65.43	0
S5	ECON1	EVAP1	287889.9663	172.3689	39.8197	166.8456	0
S6	EVAP1	SPHT1	287889.9663	172.3689	115.5952	2699.6013	1
S7	SPHT1	SINK1	287889.9663	172.3689	375.0003	3225.5362	1

Equipment/Ports	Flow	Pressure	Temperature	Enthalpy	Quality
	kg/hr	kPa	C	kJ/kg	
ECON1 [ECON]: Economizer					
Gas Inlet	1508400.0112	101.32	126.5952	128.9594	0
Gas Outlet	1508400.0112	101.32	110	109.4099	0
Water Inlet	287889.9663	172.3689	15.5556	65.43	0
Water Outlet	287889.9663	172.3689	39.8197	166.8456	0
EVAP1 [EVAP]: Evaporator					
Gas Inlet	1508400.0112	101.32	512.7965	617.1897	0
Gas Outlet	1508400.0112	101.32	126.5952	128.9594	0
Water Inlet	287889.9663	172.3689	39.8197	166.8456	0
Steam Outlet	287889.9663	172.3689	115.5952	2699.6013	1
Blowdown Outlet	0	172.3689	115.5952	485.023	0

Figure 28: Stream Report

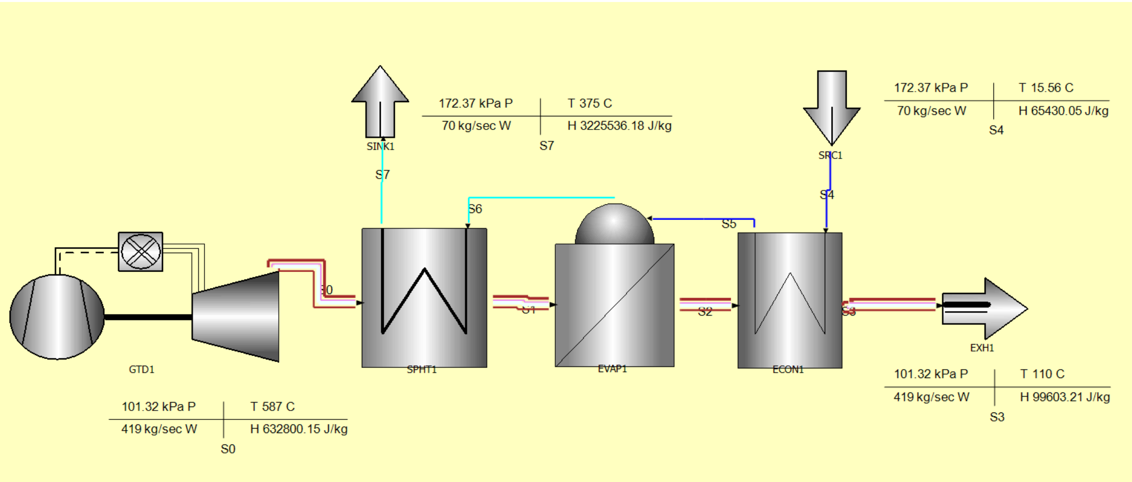


Figure 29: Stream Data in workspace

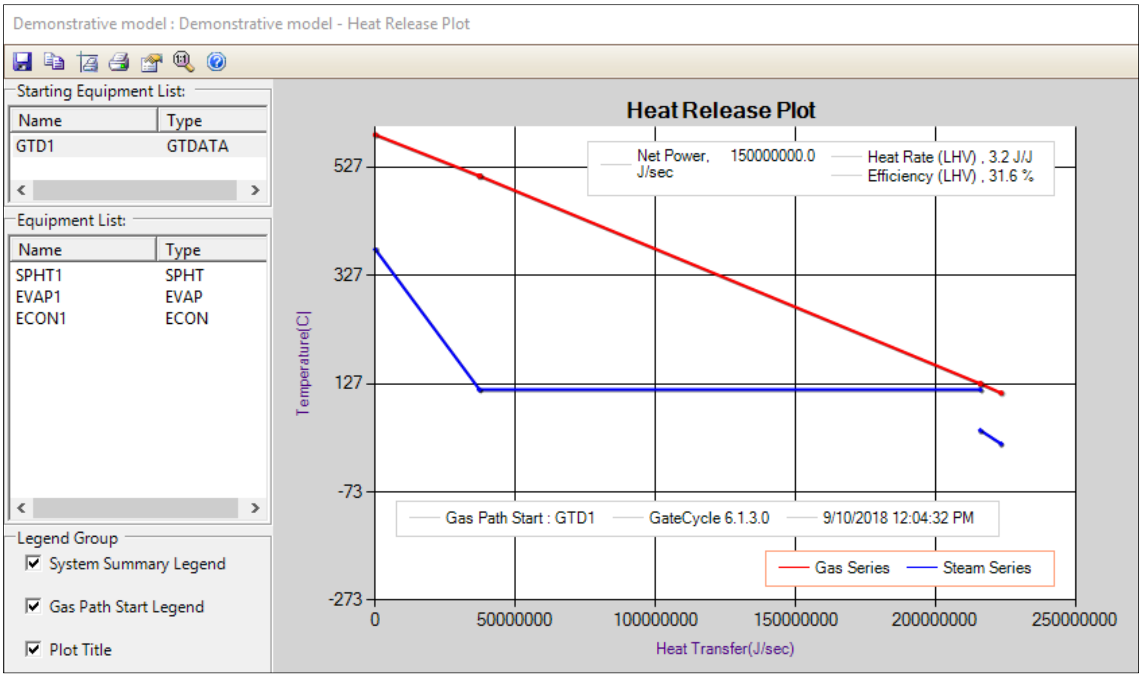


Figure 30: Heat Release Plot

2.6 Macros

Macro is a powerful feature which can automate any "hand calculation" in GateCycle. To open Macro Editor block (shown in Figure 31), simply click on *"Inputs → Macros…"*. To set up a new macro, select the *"New Macro"* icon.

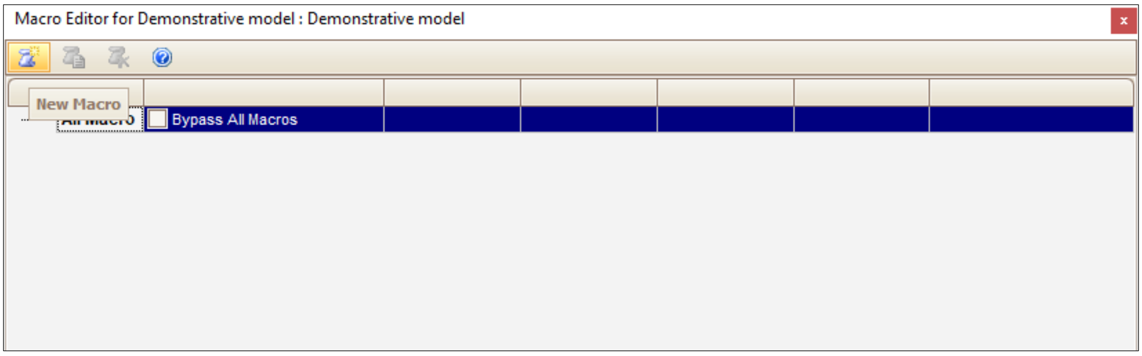


Figure 31: Macro Editor window

After that, Macro Definition Dialog box appears with several sets of inputs. To begin, new variables must be defined. Click on *"New Variable"* (former *"New Macro"*) icon and set two variables - A and B. To define variable, you need to choose a particular equipment and its characteristic (e.g. one of the flow rate). The first variable can be defined as an "unknown" being searched for and the second variable as a tool, which is being modified in a range of interval and either directly or indirectly influences the value of "unknown".

To further explain this topic, we have an illustrative example. We want to obtain a specific steam flow from the superheater (SPHT1) based on amount of fuel supplied to the gas turbine (GTD1) in model displayed in Figure 29. We have a variable A as an output, which is going to be controlled by an input, variable B. Interval range of variable B (Lower and Upper Limit) has to be defined together with a desired value of variable A (X). See the finished macro in Figure 32. We can read it as: *"Control the Steam Outlet Flow (A) to value of 80 kg/s (X) by varying the gas turbine fuel flow rate (B) from a minimum of 0 to a maximum of 50 kg/s"*.

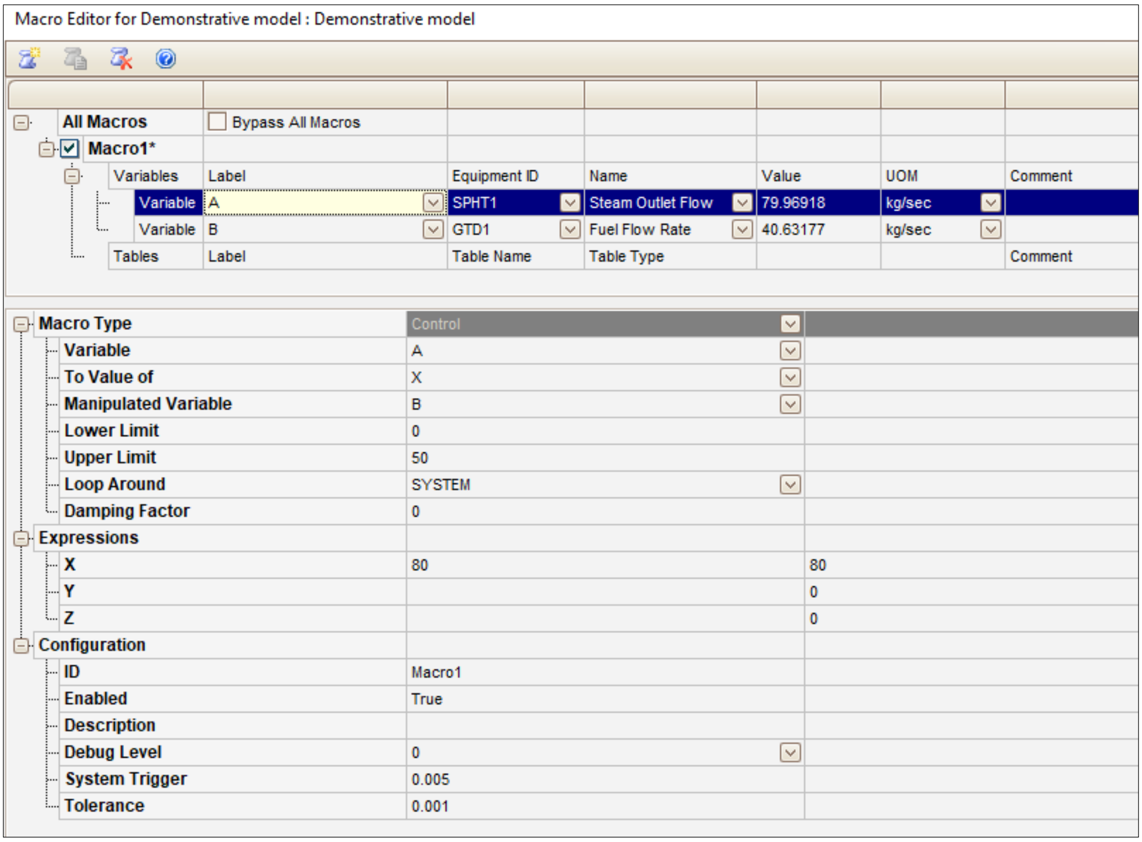


Figure 32: New Macro setting

2.7 GateCycle Model Library

Previous subchapters dealt with the detailed description of how to set up the model and run a new simulation. For those already familiar with software basis and utilities, GateCycle contains a database of many preset models. Some of them help as training tutorials with specific lectures like setting macros, mass flow control or optimization feature. Others represent variety of power plants cycles analysable by GateCycle. They may be picked as a "starting model" to save user's time and subsequently being rebuilt based on needs of the user's simulated process. Bear in mind that those models have not been fully optimised to the best energetic, nor cost effectiveness.

You can see the example of prebuilt model in Figure 33. It is an introduction to the series of models HRSG01 - HRSG06 which show increasing combined cycle efficiency depending on cycle complexity. It serves as a practice for topics like setting up mass flow balancing, deaeration control and others. You can easily find preset Model database in the Model Explorer pane after opening GateCycle.

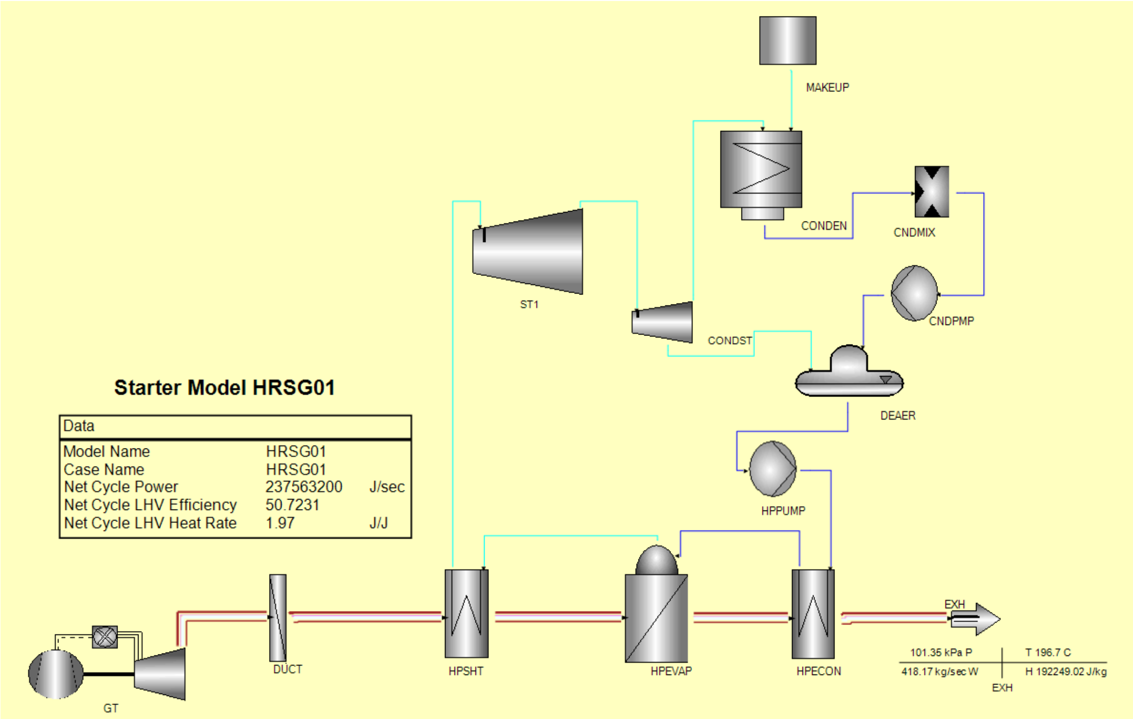


Figure 33: HRSG01 learning model

3 Modelling of superheated steam boiler in Gate Cycle software environment

This chapter is dedicated to the practical part of the thesis - application of GateCycle software for industrial superheated steam boiler simulation. In the beginning, a simple schematic boiler drawing is being introduced, together with key operating specifications such as temperature, pressure and other important data. Detailed step-by-step guide how to set up and run the simulation is listed in the subsequent subchapters. In the end of the chapter, obtained results are discussed and compared to the real operating conditions.

3.1 Description of simulated industrial steam boiler

You can see the simulated steam boiler schematic drawing in Figure 34. Main boiler components are following: 1 - Drum, 2 - Evaporator, 3a + 3b - Steam Superheaters, 4a + 4b - Economizers, 5 - Burners.

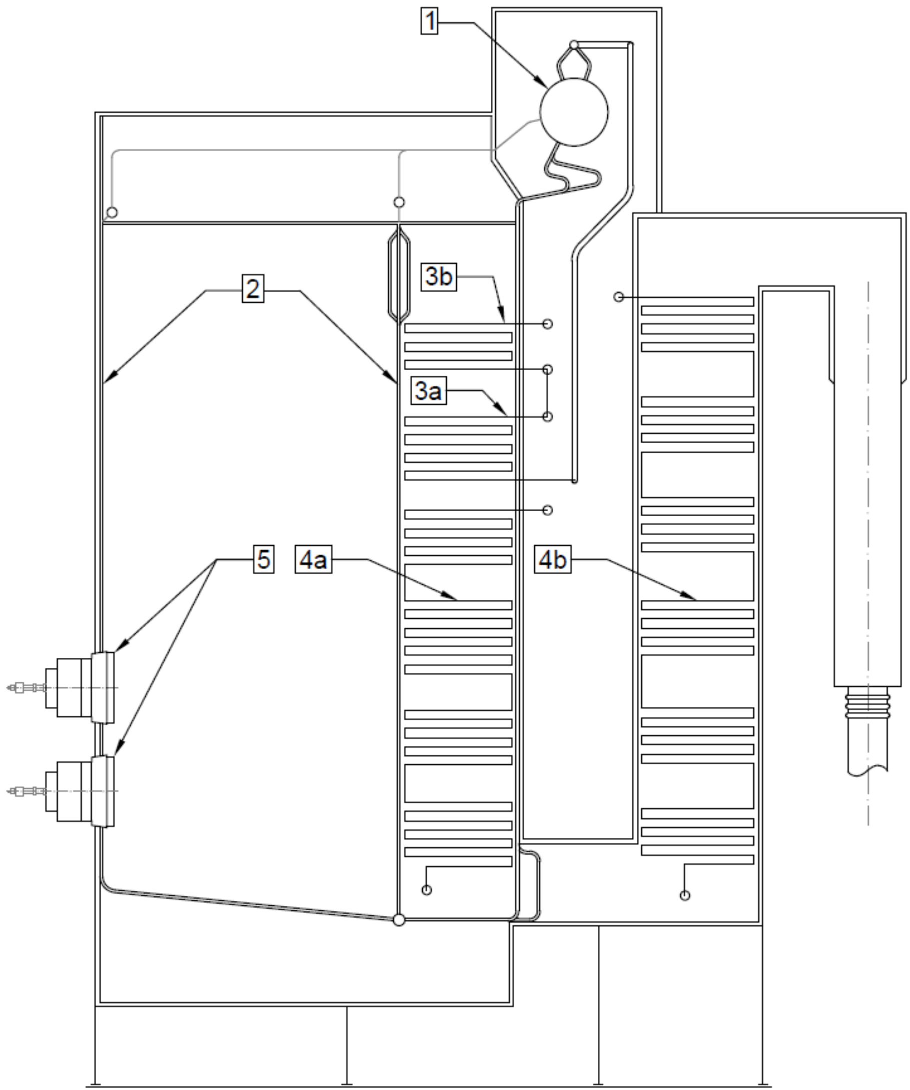


Figure 34: Schematic drawing of simulated boiler

Boiler key operating parameters are listed in Table 1 and fuel specifications are stated in Table 2 (lower heating value and fuel composition in mole fractions) and Table 3 (pressure and temperature of supplied fuels). Further information is provided in Appendix A - Detailed steam boiler specification (available only in Czech language).

Table 1: Simulated boiler key operating parameters

Steam produced	120	t/h
Temperature of superheated steam	375	+ 25°C – 10°C
Pressure of superheated steam	3.82	MPa
Temperature of feed water	145	°C

Table 2: Fuel specifications (lower heating value and molar composition)

Fuels			
Tar heating oil	Lower heating value		34 200 kJ/kg
	Composition	C	94%
		H_2	5%
		S	0.5%
		others	0.5%
Natural gas	Lower heating value		32 510 kJ/kg
	Composition	CH_4	97.8%
		C_2H_6 and higher carbohydrates	1.1%
		$CO_2 + N_2$	1.1%
Heavy fuel oil	Lower heating value		40 612 kJ/kg
	Composition	H_2O	1 %
		S	2.35 %
		Mechanical impurities	1 %

Table 3: Fuel specifications (pressure and temperature)

	Tar heating oil	Natural gas	Heavy fuel oil
Pressure	17 bar	1.7 bar	17 bar
Temperature	230 °C	20 °C	140 °C

Value of lower heating value of natural gas stated in Table 2 is suspiciously low. It is highly probable that the value is incorrect, therefore, we let GateCycle to determine LHV of natural gas from given molar composition. Accuracy of estimation of other fuels LHVs is unknown to thesis author. Since GateCycle cannot calculate their LHVs, fuels must be specified as fluid fuels with given LHV. As a result, simulated fuel consumptions may differ from operating data.

3.2 Building the simulation model

In following sections, complete model of simulated industrial steam boiler is set up in multiple steps. The modelling work is structured subsequently. First, gas / exhaust stream path is built with all heat exchange equipment. Second, feed water / steam stream path is added. Finally, process apparatuses necessary for cleaning feed water and steam from impurities are modelled.

3.2.1 Gas / exhaust stream

Click on "*View → Equipment Toolbox*" and add following equipment icons into your workspace from left to the right - *Gas*, *Fossil Boiler*, two *Superheaters* in a row, *Economizer*, *Splitter*, another *Economizer* and *Exhaust*. Connect the equipment with gas stream and notice the red colour. See the situation displayed in Figure 35.

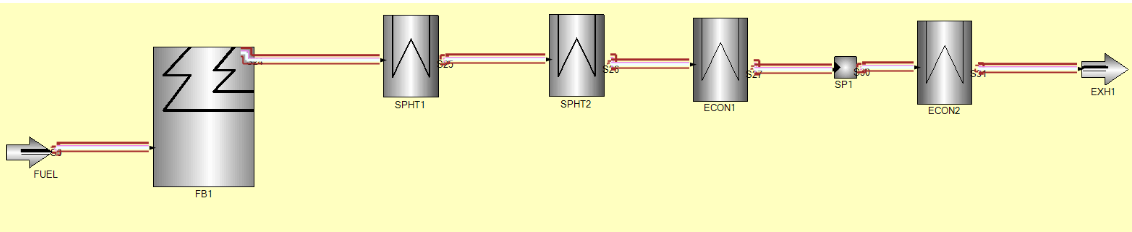


Figure 35: Gas / exhaust stream part 1

In next step, add more icons - *Gas* (for combustion excess air), followed by *Compressor* and *Splitter*. Place another *Compressor* below them for exhaust recycle stream. Connect all the equipment according to Figure 36. Now, we have successfully built a complete exhaust path. The fuel mixed with excess combustion air burns in boiler furnace, in multiple heat exchangers transfers the heat and leaves the steam boiler. Part of the exhaust gas is being recycled.

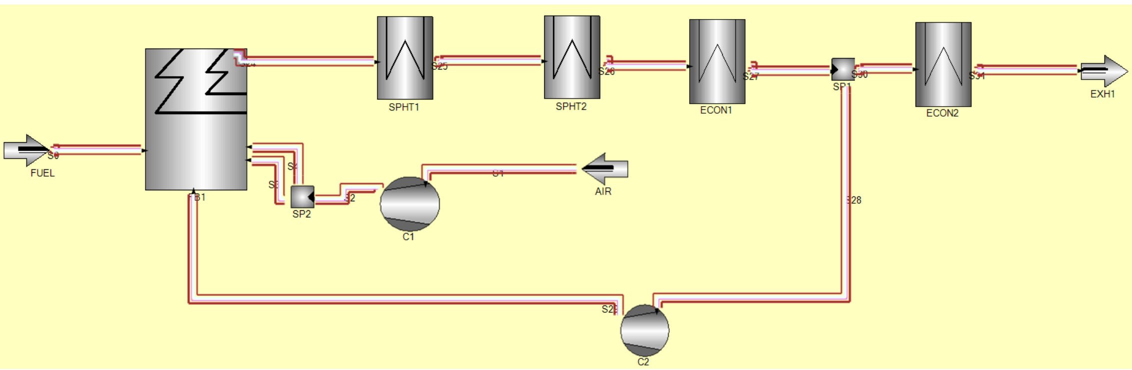


Figure 36: Gas / exhaust stream part 2

3.2.2 Feed water / steam stream

Now, let's start with water path. Drag *Makeup*, *Pump* and *Valve* icons and place them before the first *Economiser* from the right. Next, add *Splitter* in halfway from the first

Economiser into the second and *Drum* between the second E*conomiser* and *Fossil Boiler*. Connect the icons through their water ports and your model should look like Figure 37.

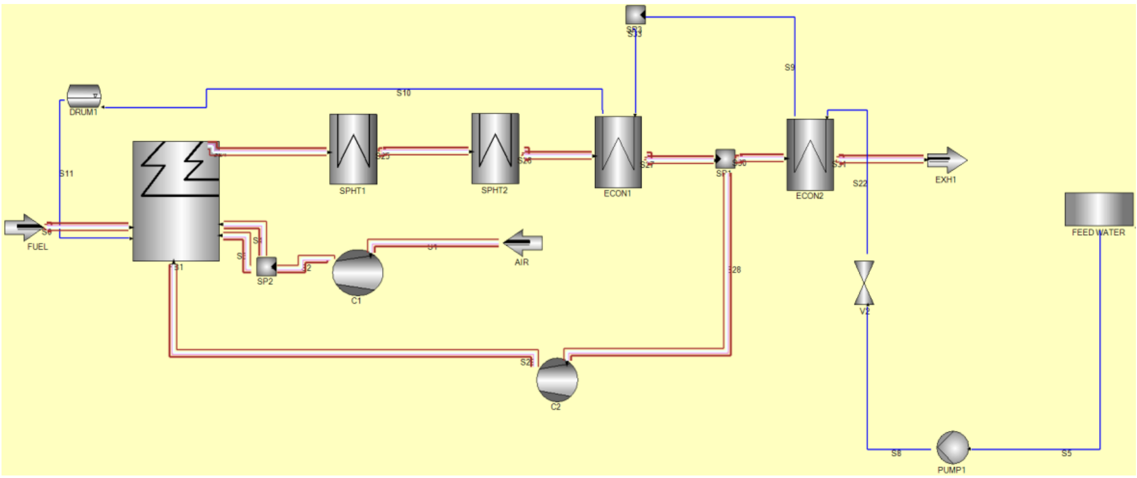


Figure 37: Feed water stream

To close water and steam path, we need to add *Temperature control* icon between two *Superheaters*, followed by *Valve* and *Sink* icons. Connect them together and you should obtain the situation shown in Figure 38.

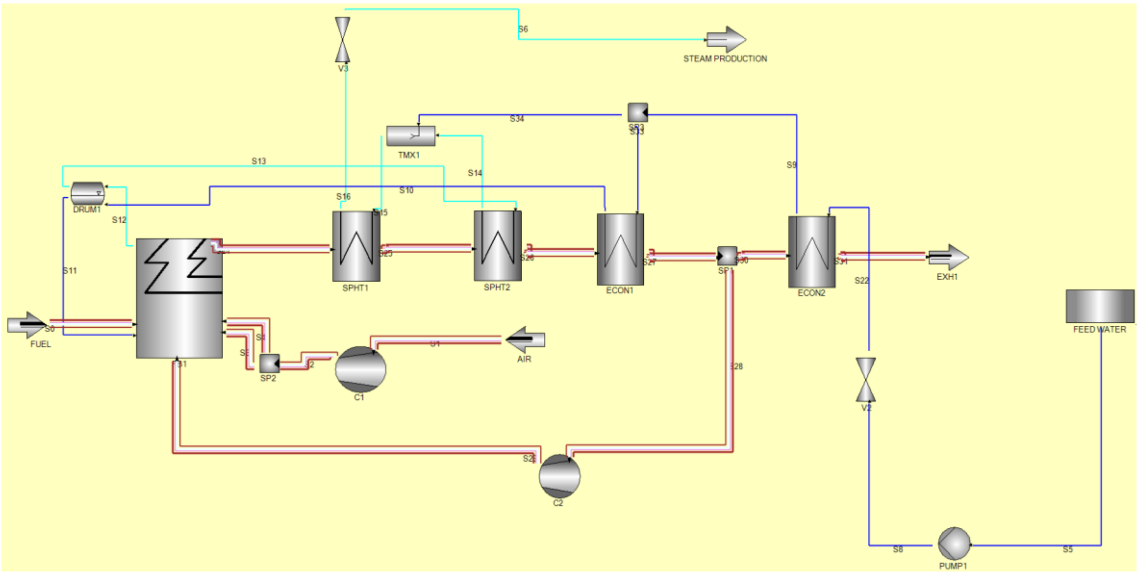


Figure 38: Feed water / steam stream

To finish the model, it is necessary to add some more equipment responsible for cleaning the cycle of water and steam impurities. Therefore, drag and drop *Flash Tank*, *Sink* and *Deaerator* icons in the lower part of the workspace. In the upper part of the workspace, place *Header* (may be used ordinary *Splitter* as well) and one more *Valve* icon. Connect all the equipment (a few ports must be reconnected) and your model should correspond to Figure 39.

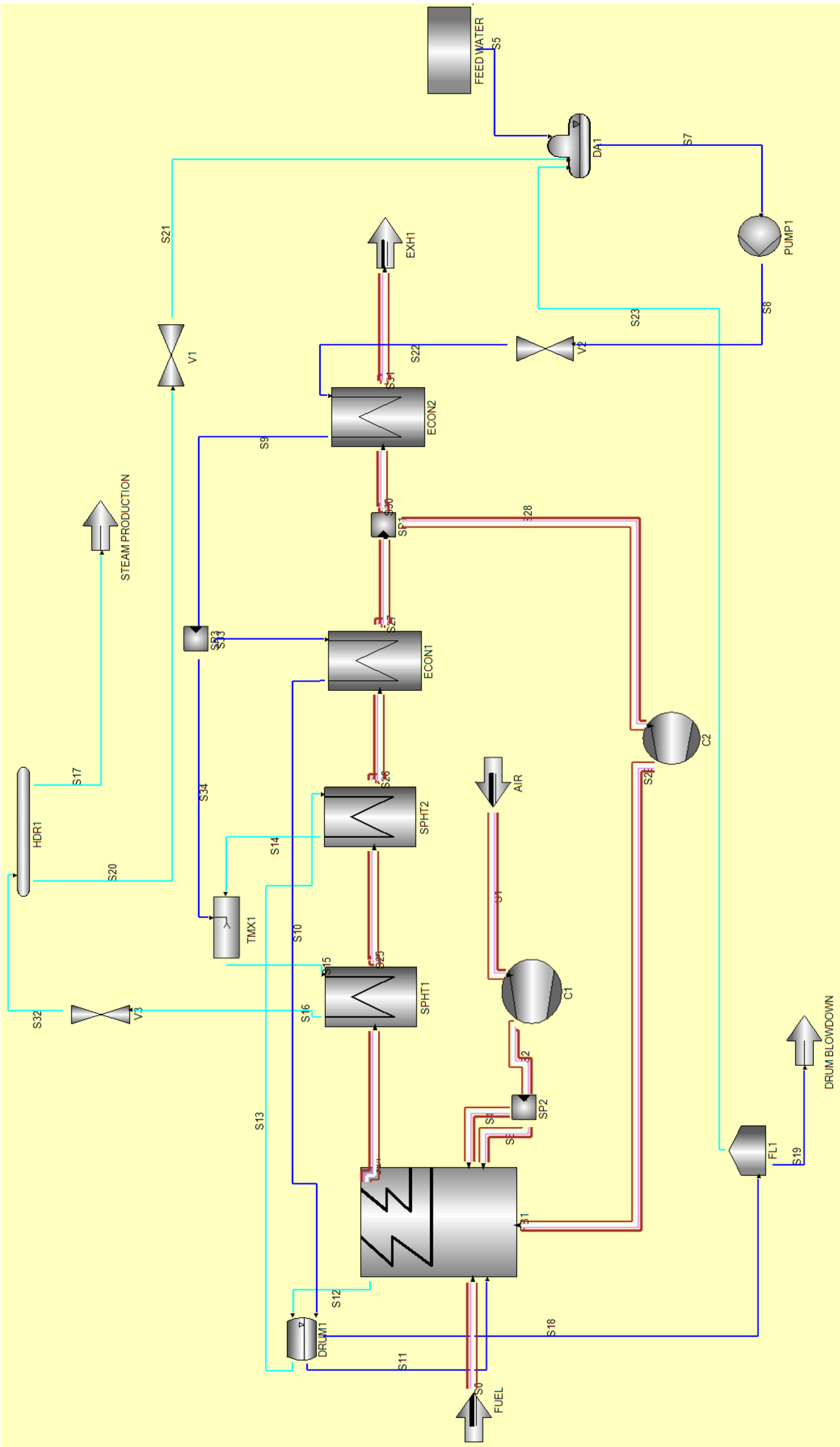


Figure 39: Final model of simulated boiler

3.3 Model data supplying

In this subchapter, all essential data are entered into boiler model to run the simulation successfully. Data are divided into 3 categories - general system properties, gas/exhaust stream and water/steam stream. Order of individual equipment data supplying corresponds to arrangement in previous subchapter concerning gas / exhaust and feed water / steam streams.

Due to the high number of settings and inputs, stylistic format of text in subsequent sections is simplified as follows:

“<u>Equipment name</u> (assigned title in the workspace; corresponding figure):

- Name of the folder in Properties window → Chosen specific option
  - Name of the subfolder → concrete value inputted”

Some settings are followed by short comment to the origin of data (set by default / extracted from boiler data paper, …). A few equipment input values were recommended by thesis supervisor based on either more detailed boiler calculations from institute commercial project linked to the simulated boiler (which were not provided to thesis author) or common engineering steam boiler designing practice.

3.3.1 General settings

<u>System Properties</u> (Figure 40):

- Steam Properties Method → 1993 ASME steam property formulations (default)
- Gas Properties Method → NASA properties: S. Gordon, B. J. McBride (default)
- Real Gas Property Method → Ideal Gas - No Real Gas Corrections (using any possible GateCycle correction did not result in a remarkable difference in fuel consumption but increased computation time significantly)
- Reference Conditions Method → Input Reference Conditions
  - Reference Temperature → 0.01 °C (input warning in *Running cycle window* appears because GateCycle default reference temperature is 60 F which equals to 15.56 °C)
  - Reference Pressure → 101.32 kPa
- System Gas - Fuel Gas Composition Flag → Mole Fractions
  - CH_4 Mole Fraction → 0.978
  - Ethane Mole Fraction → 0.011
  - CO_2 Mole Fraction → 0.007
  - N_2 Mole Fraction → 0.004
- Fuel Gas Heating Value Flag → Input Lower Heating Value (LHV)
  - Fuel Gas LHV → left empty, will be calculated from fuel molar composition

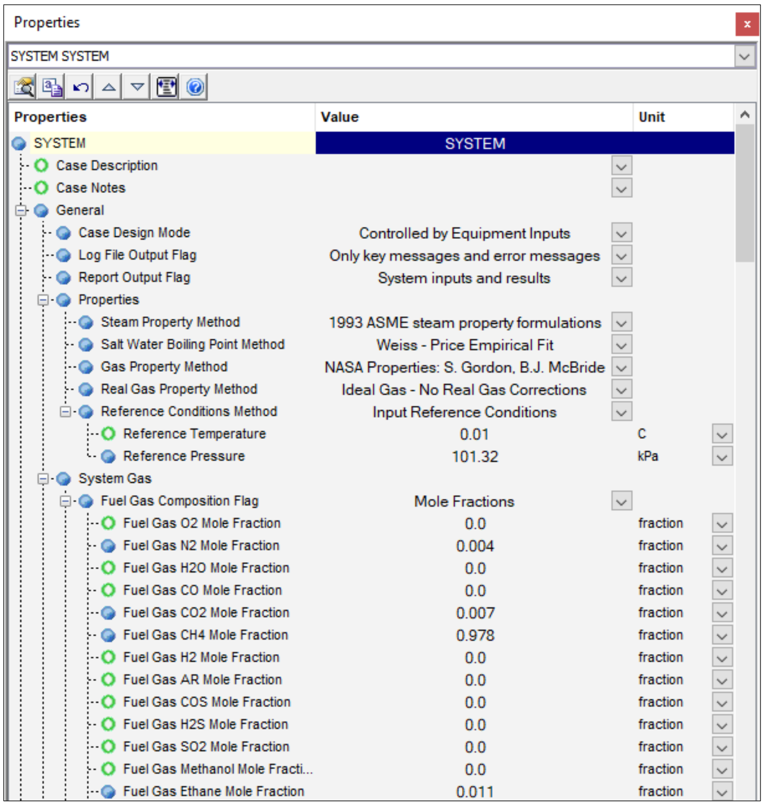


Figure 40: System Properties

3.3.2 Gas / exhaust stream data

Gas (FUEL; Figure 41):

- Fluid Type → Read Gas Fuel from System
- Calculation (flash) Metod → Pressure - Temperature
- Heat Rate Adjustment Flag → Flow does not affect overall heatrate (default)
- Pressure → 1.7 bar (boiler data paper)
- Temperature → 20 °C

Fossil Boiler (FB1; Figure 42):

- Water Wall Method Flag → Exit Quality
- Desired Water Wall Exit Quality → 0.898 (supplied by thesis supervisor)
- Boiler Load Method Flag → Total Fuel Flow
  - Desired Total Fuel Flow → left empty, will be calculated by macro
- Combustion Method Flag → Fraction Excess Air
  - Desired Excess Air Fraction → 0.06 (boiler data paper)
  - Desired Exhaust Gas Temperature → 957 °C (boiler data paper)
- Radiant Heat Loss Fraction → 0.0015 (supplied by thesis supervisor)

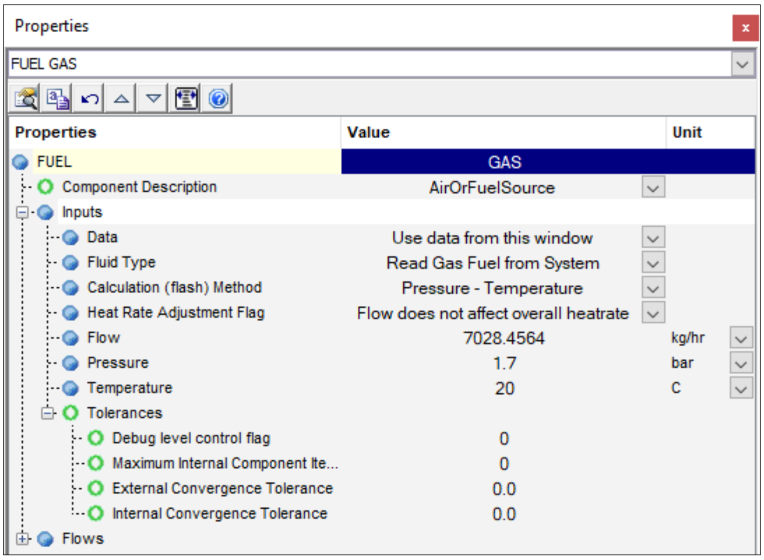


Figure 41: FUEL Properties

<u>First Superheater</u> (SPHT1; Figure 43):

- Superheater Method Flag → Steam Outlet Temperature
  - Desired Steam Outlet Temperature → 375 °C
- Configuration Method → Pure Counter Flow
- Cold side pressure loss → 50 kPa (no avalaible data, guessed value to obtain operating pressure of boiler steam drum)
- Energy loss fraction → 0.0002 (supplied by thesis supervisor)

<u>Second Superheater</u> (SPHT2; Figure 44):

- Superheater Method Flag → Steam Outlet Temperature
  - Desired Steam Outlet Temperature → 340 °C
- Configuration Method → Pure Counter Flow
- Cold side pressure loss → 50 kPa (guessed value)
- Energy loss fraction → 0.0002 (supplied by thesis supervisor)

<u>First Economizer</u> (ECON1; Figure 45):

- Economizer Modeling Method → Water Outlet Temperature
  - Desired Water Outlet Temperature → 253 °C
- Configuration Method → Pure Counter Flow
- Cold side pressure loss → 100 kPa (guessed value)
- Energy loss fraction → 0.0003 (supplied by thesis supervisor)

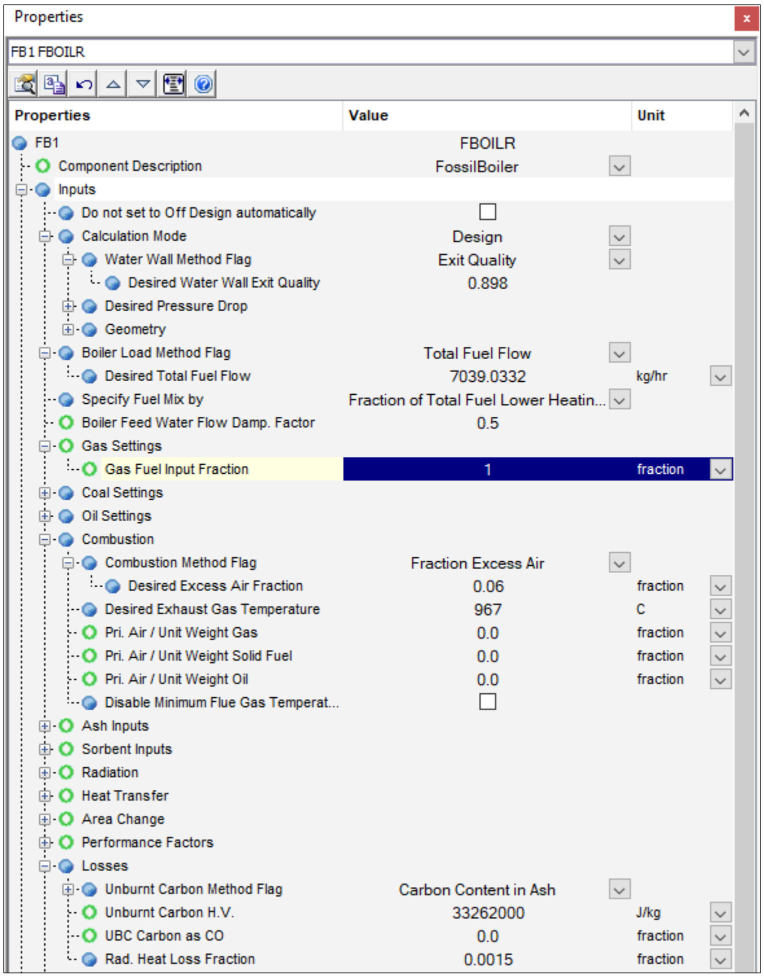


Figure 42: FB1 Properties

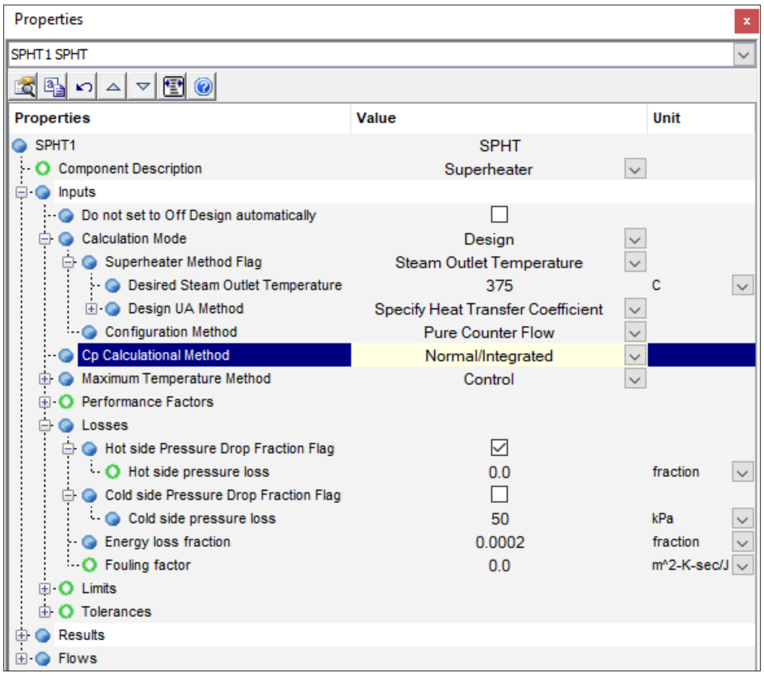


Figure 43: SPHT1 Properties

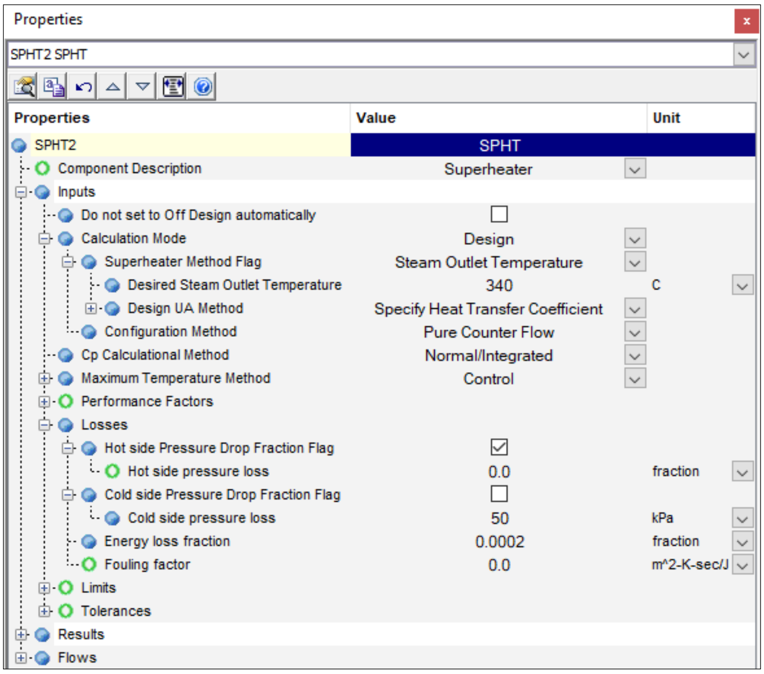


Figure 44: SPHT2 Properties

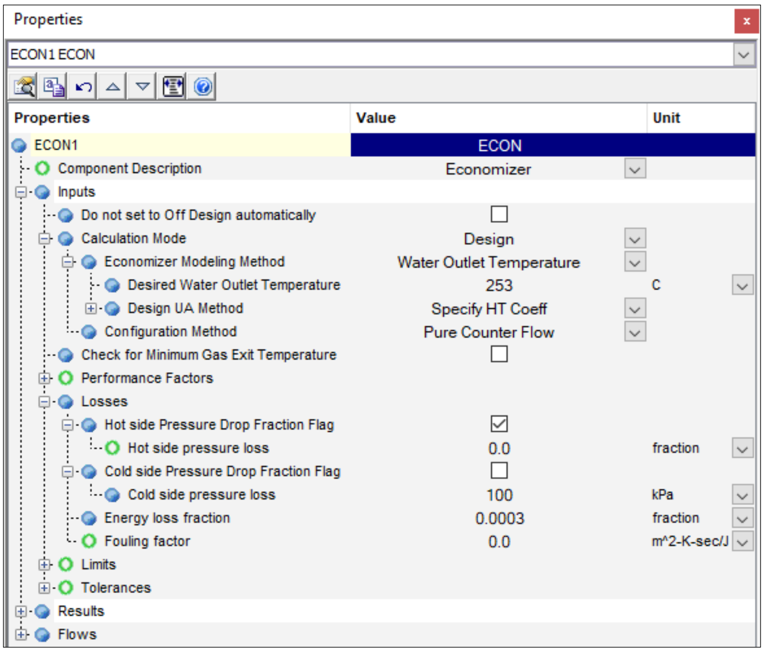


Figure 45: ECON1 Properties

<u>Splitter</u> (SP1; Figure 46):

- Primary Port Control Method → Remainder Port
- Secondary Port Control Method → Specify Flow Fraction
    - Secondary Port Desired Fraction → 0.106 (supplied by thesis supervisor)

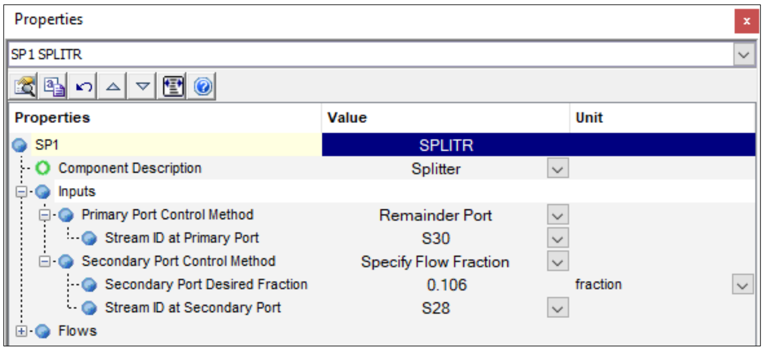


Figure 46: SP1 Properties

<u>Second Economizer</u> (ECON2; Figure 47):

- Economizer Modeling Method → Gas Outlet Temperature
    - Desired Gas Exit Temperature → 170 °C
- Configuration Method → Pure Counter Flow
- Cold side pressure loss → 100 kPa (guessed value)
- Energy loss fraction → 0.0003 (supplied by thesis supervisor)

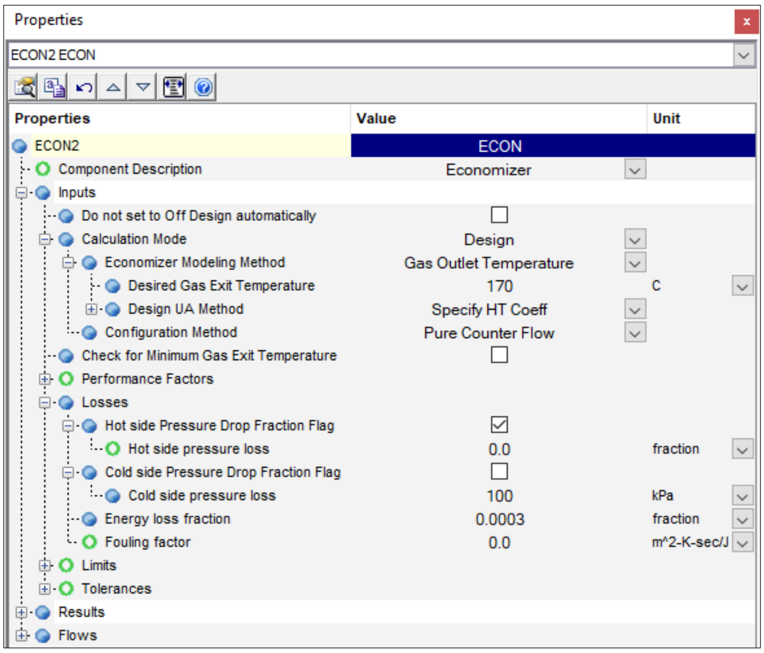


Figure 47: ECON2 Properties

<u>Exhaust</u> (EXH1; Figure 48):

- Pressure Control Method → Control Pressure to Ambient

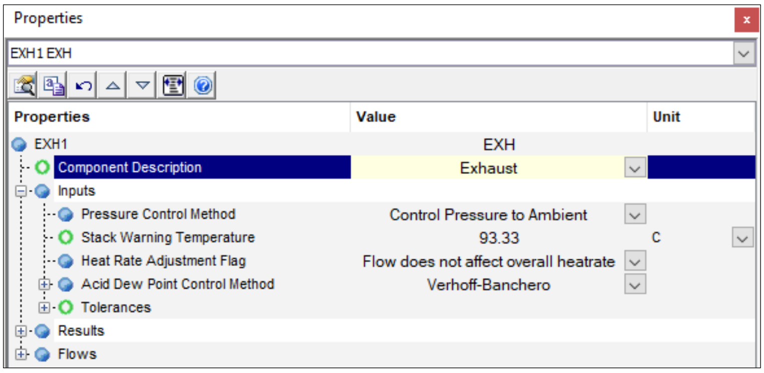


Figure 48: EXH1 Properties

<u>Gas</u> (AIR; Figure 49):

- Fluid Type → User-specified Gas
  - Fuel LHV Method Flag → User Defined LHV
    - Lower Heating Value → 0 J/kg
- Calculation (flash) Metod → Pressure - Temperature
- Pressure → 101.32 kPa
- Temperature → 130 °C (boiler data paper)

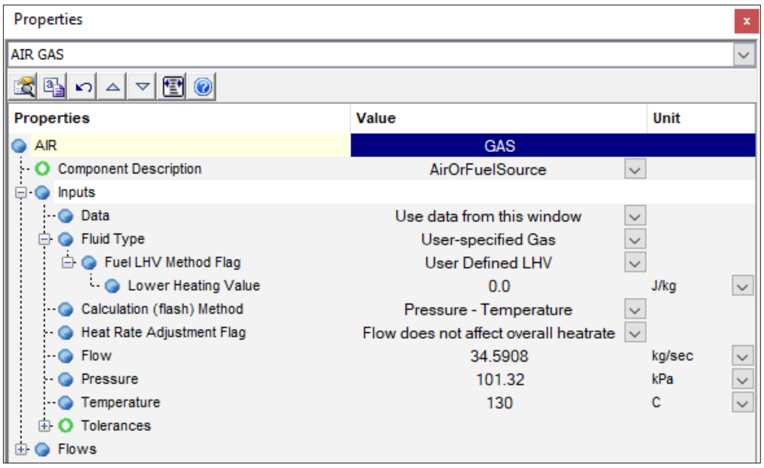


Figure 49: AIR Properties

<u>Compressor</u> (C1; Figure 50):

- Design Pressure Method → 1 - Desired Outlet Pressure
  - Desired Outlet Pressure → 105 kPa
- Design Flow Method → 0 - Accept Incoming Flow

<u>Splitter</u> (SP2; Figure 51):

- Primary Port Control Method → Downstream Flow Control
- Secondary Port Control Method → Downstream Flow Control

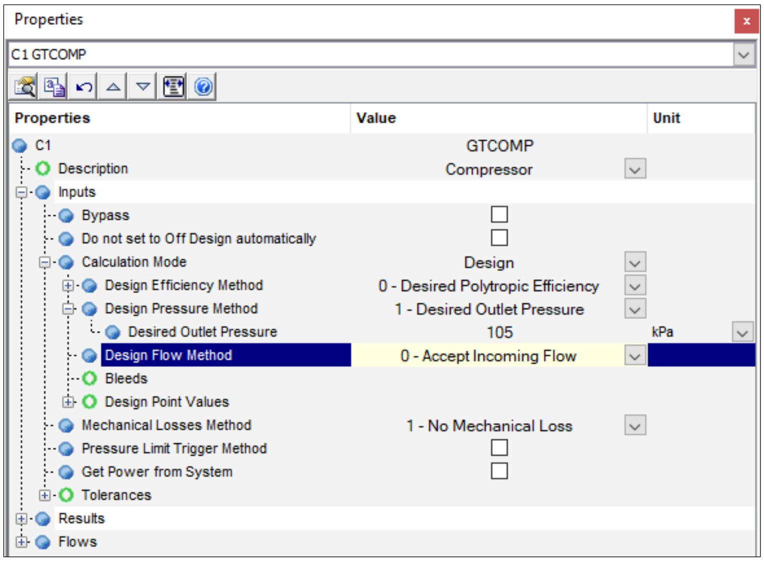


Figure 50: C1 Properties

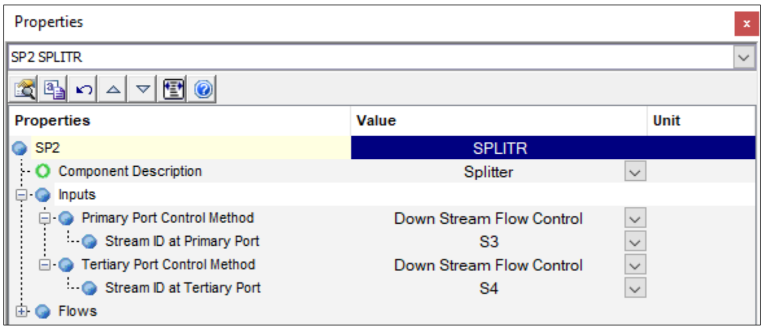


Figure 51: SP2 Properties

<u>Compressor</u> (C2; Figure 52):

- Design Pressure Method → 1 - Desired Outlet Pressure
    - Desired Outlet Pressure → 105 kPa
- Design Flow Method → 0 - Accept Incoming Flow

3.3.3 Feed water / steam stream data

<u>Makeup</u> (FEED WATER; Figure 53):

- Makeup Block Type → Automatic
- Calculation (flash) Metod → Temperature and Pressure
- Outlet Pressure → 200 kPa
- Outlet Temperature → 20 °C

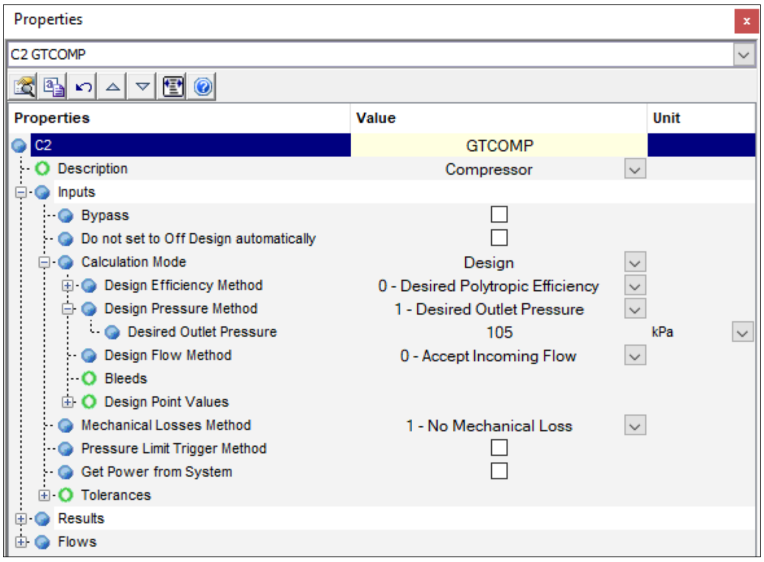


Figure 52: C2 Properties

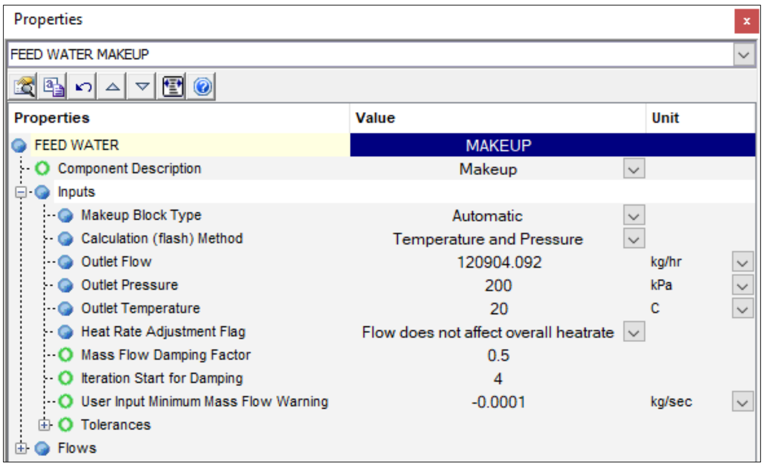


Figure 53: FEED WATER Properties

<u>Pump</u> (PUMP1; Figure 54):

- Pump Exit Pressure Method Flag → Pump Exit Pressure
  - Desired Pump Exit Pressure → 4400 kPa (supplied by thesis supervisor)
- Control Method Flag → No Control Valve

<u>Valve</u> (V2; Figure 55):

- Inlet Pressure Method → Accept Incoming Pressure
- Pressure Control Method → No Pressure Loss
- Temperature Control Method → Outlet Temperature
  - Desired Exit Temperature → 145 °C (boiler data paper)

<u>Splitter</u> (SP3; Figure 56):

- Primary Port Control Method → Downstream Flow Control
- Secondary Port Control Method → Remainder Port

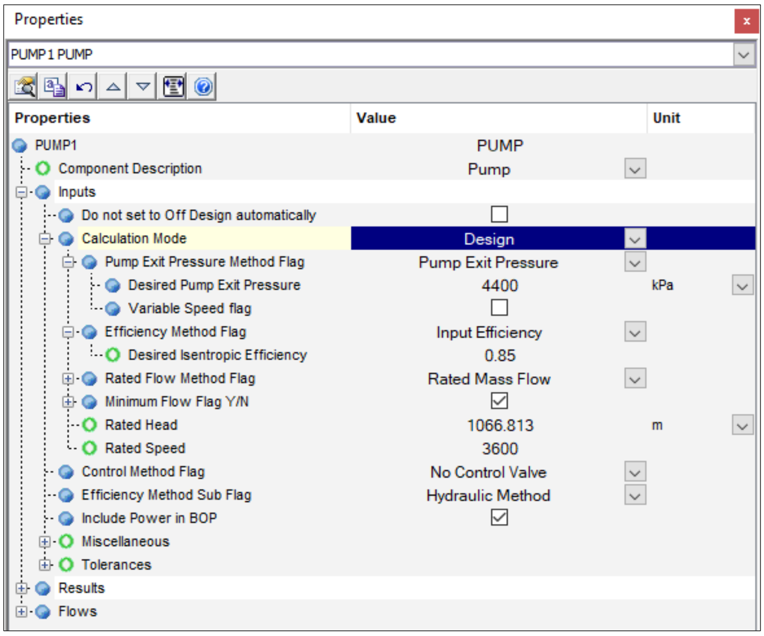


Figure 54: PUMP1 Properties

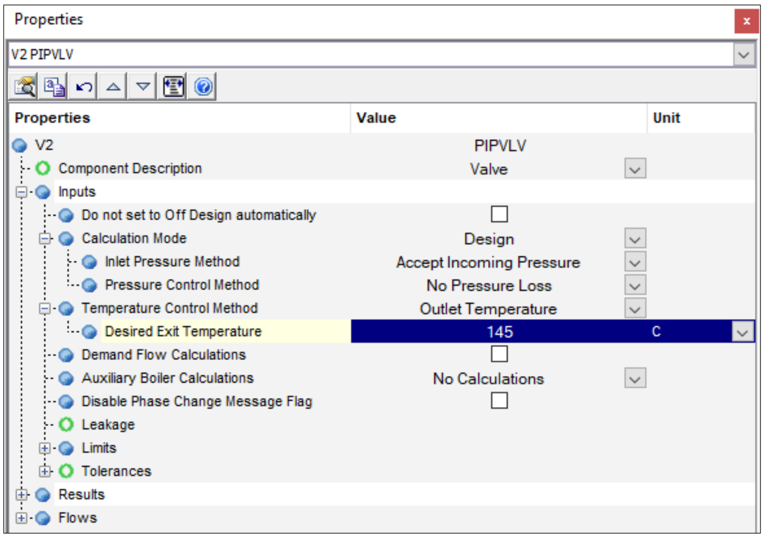


Figure 55: V2 Properties

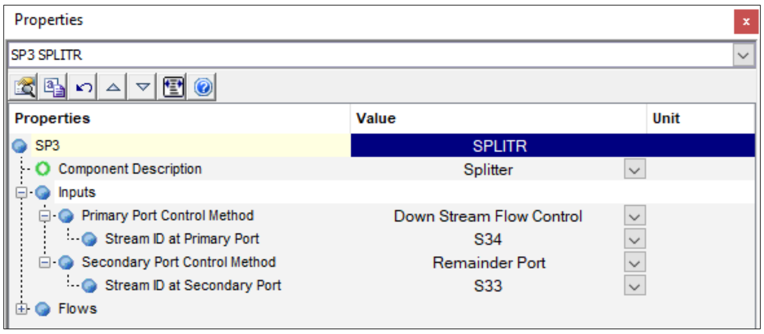


Figure 56: SP3 Properties

<u>Drum</u> (DRUM1; Figure 57):

- Drum Blowdown Method → Fraction of Steam
    - Desired Drum Blowdown Fraction of Steam → 0.01 (usual value in boiler designing practice)
- Drum Pressure Method → Outlet Pressure
- Desired Operating Pressure → 3920 kPa

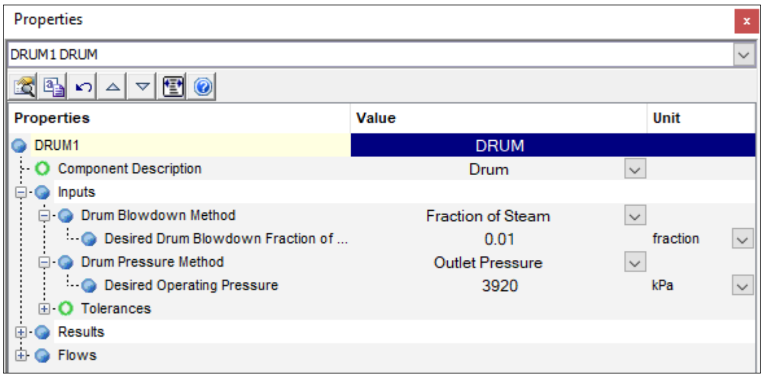


Figure 57: DRUM1 Properties

<u>Temperature control</u> (TMX1; Figure 58):

- Temperature Control Method → Outlet Temprature
    - Desired Outlet Temprature → 260 °C
- Pressure Control Method → No Pressure Loss

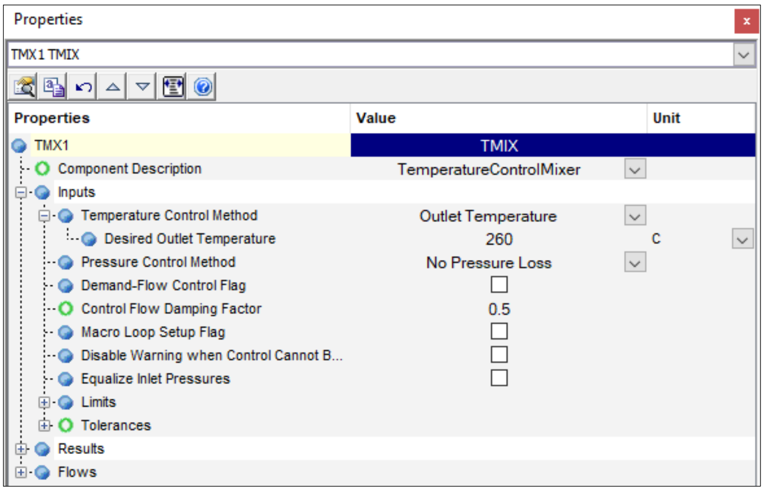


Figure 58: TMX1 Properties

<u>Valve</u> (V3; Figure 59):

- Inlet Pressure Method → Accept Incoming Pressure
- Pressure Control Method → Specified Outlet Pressure
    - Desired Exit Pressure → 3820 kPa
- Temperature Control Method → No Enthalpy Change

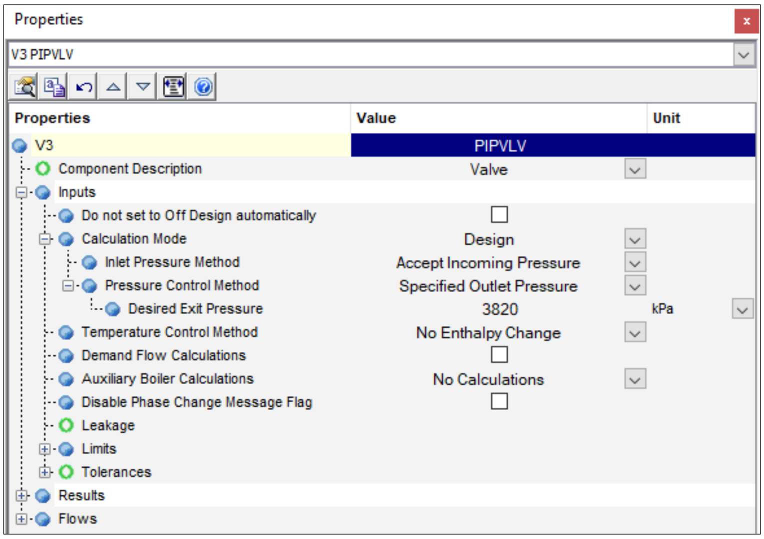


Figure 59: V3 Properties

<u>Sink</u> (STEAM PRODUCTION; Figure 60):

- No input data necessary

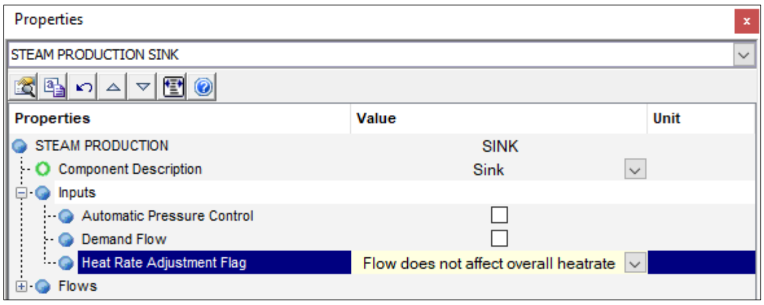


Figure 60: STEAM PRODUCTION Properties

<u>Flash Tank</u> (FL1; Figure 61):

- Flash Temperature Method → Adiabatic Flash
- Flash Pressure Method → Outlet Pressure
    - Desired Flash Operating Pressure → 200 kPa
- Remove Water Out of Condensate → Tick the box

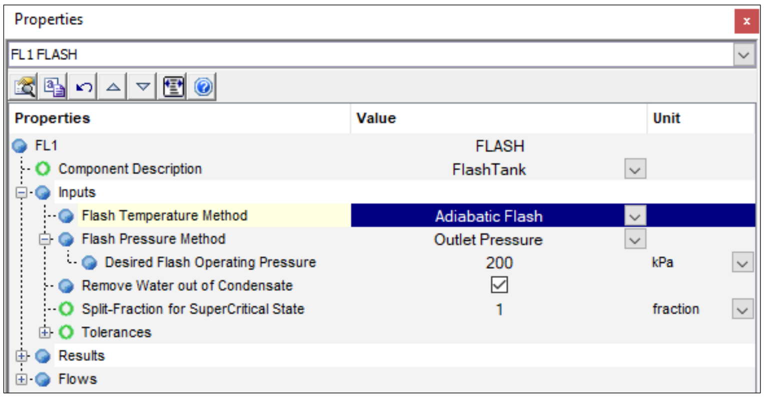


Figure 61: FL1 Properties

Sink (DRUM BLOWDOWN; Figure 62):

- No input data necessary

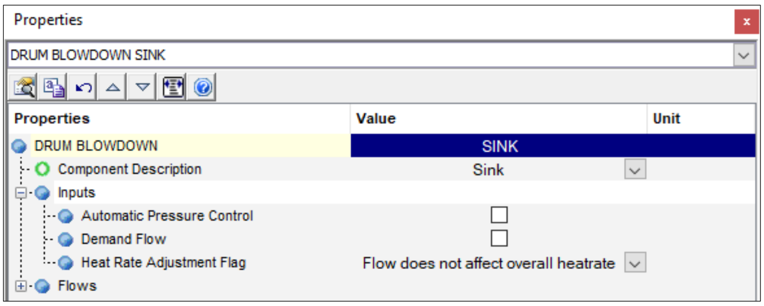


Figure 62: DRUM BLOWDOWN Properties

Deaerator (DA1; Figure 63):

- DA Method Flah → 2 - Constant Pressure: Demand Pegging Steam Flow
- Vent Method Flag → Specified fraction of the inlet Boiler Feed Water Flow
    - Desired Vent Fraction of Boiler Feed Water → 0
    - Pegging Steam Control Method → Control Auxiliary Steam Flow
    - Desired Operating Pressure → 101.32 kPa

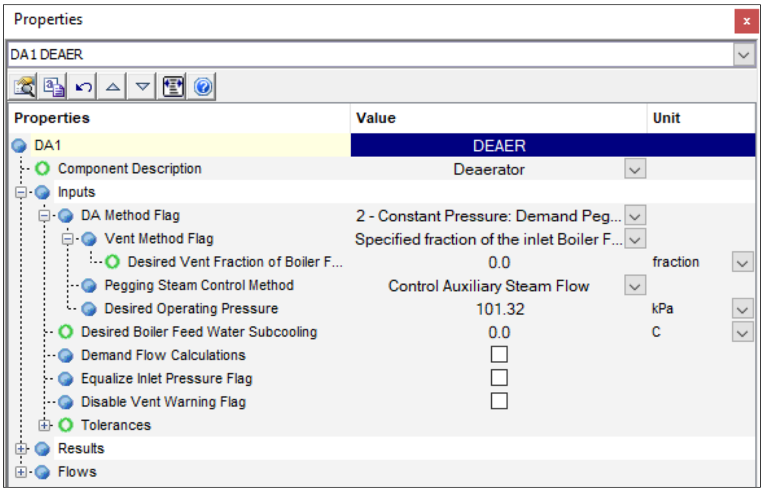


Figure 63: DA1 Properties

Header (HDR1; Figure 64):

- First Outlet Control Flag → Downstream Flow Control
- Eighth Outlet Control Flag → Remainder Port

Valve (V1; Figure 65):

- Inlet Pressure Method → Accept Incoming Pressure
- Pressure Control Method → No Pressure Loss
- Temperature Control Method → No Enthalpy Change

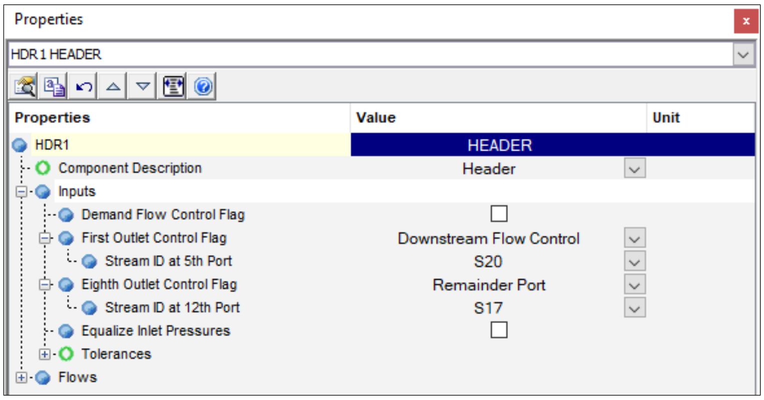


Figure 64: HDR1 Properties

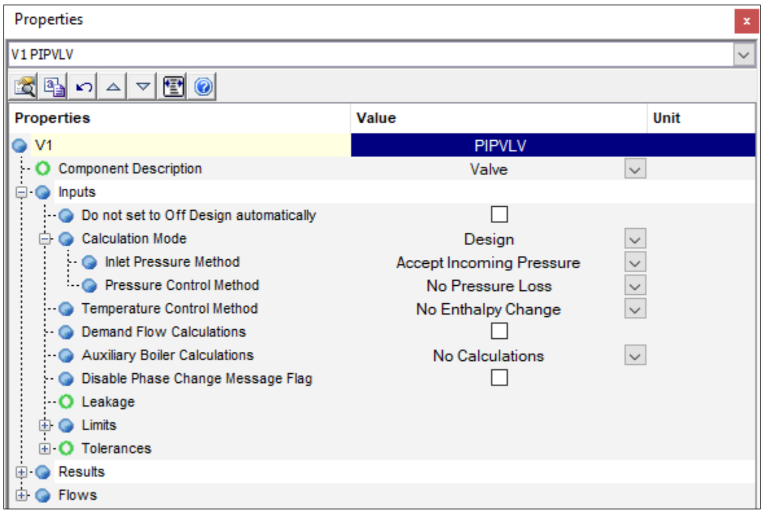


Figure 65: V1 Properties

3.3.4 Macro defining and few notes to model simplification

To finish simulation building phase properly, we need to set up a macro to achieve a boiler production of 120 tons of steam per hour. To do so, we need to set following:

Macro Settings (Figure 66):

- Variable A:
  - Equpipment ID → STEAM PRODUCTION
  - Name → Inlet Flow
- Variable B:
  - Equpipment ID → FB1
  - Name → Desired Total Fuel Flow
- Variable → A
- To Value of → X
- Manipulated Variable → B
- Lower Limit → 6900
- Upper Limit → 7100

- Expression X → 120000
- Tolerance → 0.0001

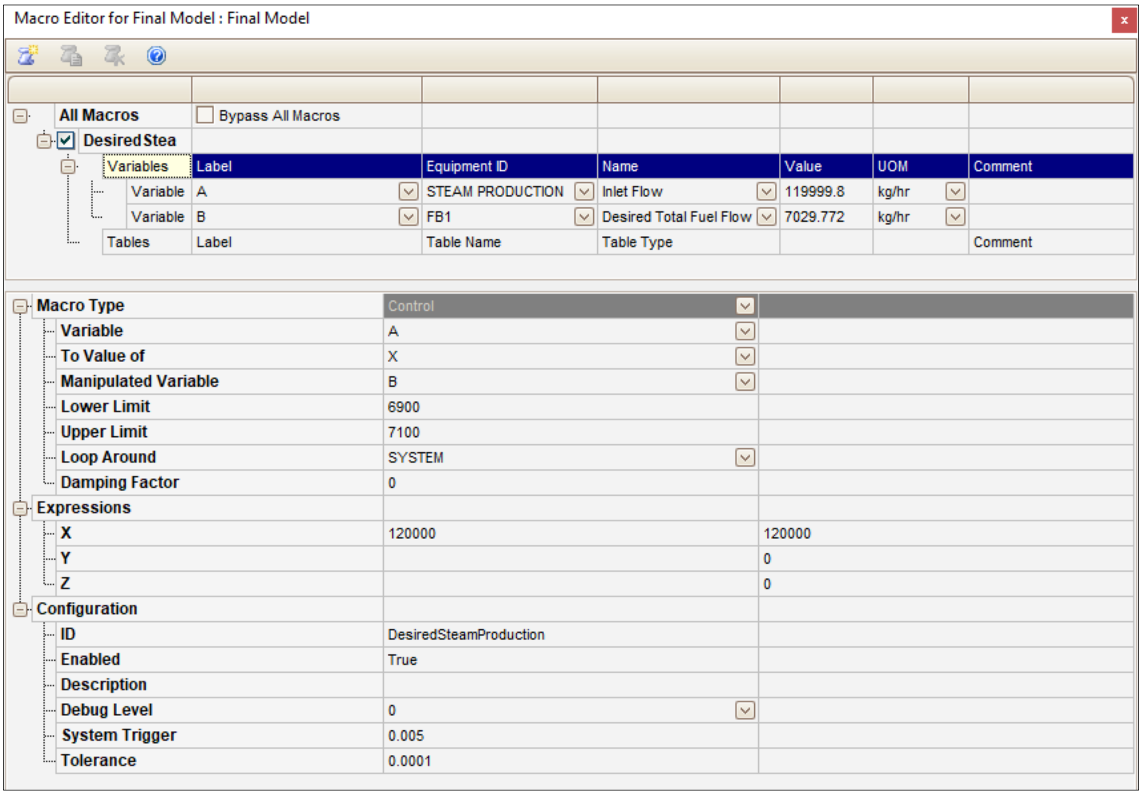


Figure 66: Macro Setting

Before the results analysis, a few model simplifications should be discussed. Due to the limited amount of boiler specification data provided, this thesis deals only with steam boiler energy balances and calculations. No detailed information about pressure levels and drops in specific pieces of equipment was provided. Therefore, as you could notice, almost no pressure, nor mechanical losses, were applied in equipment like valves, compressors or pump. The only pressure losses considered were in few apparatuses on water / steam path, to roughly estimate operating conditions of steam drum and other equipment which could have an impact on boiler energy calculations.

With more complex boiler and particular equipment data specification, you could, for instance, design optimal size of heat exchange surfaces in boiler furnace or heat exchangers, necessary power to drive compressors and pumps and much more.

As a consequence of lack of more detailed boiler equipment operating data provided and only energy balances considered, the only GateCycle calculated output taken is boiler burners fuel consumption. It is consequently compared to real operating value and based on that comparison, accuracy of GateCycle calculations is evaluated.

3.3.5 Simulation of operating conditions with different fuels

Because operating conditions of few process equipment differs while boiler is supplied by tar heating oil or by heavy fuel oil, simulated model must be slightly changed. Complete operating boiler data are listed in “Appendix A - Detailed steam boiler specification”.

Tar heating oil:

- Input fuel pressure at FUEL → 17 bar
- Input fuel temperature at FUEL → 230 °C
- Desired Water Outlet Temperature at ECON1 → 250 °C
- Desired Steam Outlet Temperature at SPHT2 → 327 °C
- Desired Outlet Temperature at TMX1 → 277 °C
- Desired Exhaust Gas Temperature at FB1 → 670 °C (872 °C)
- Desired Excess Air Fraction at FB1 → 0.1
- Desired Gas Exit Temperature at ECON2 → 170 °C
- Macro Editor: Lower Limit → 10000
  Upper Limit → 11000

Heavy fuel oil:

- Input fuel pressure at FUEL → 17 bar
- Input fuel temperature at FUEL → 140 °C
- Desired Water Outlet Temperature at ECON1 → 243 °C
- Desired Steam Outlet Temperature at SPHT2 → 326 °C
- Desired Outlet Temperature at TMX1 → 276 °C
- Desired Exhaust Gas Temperature at FB1 → 740 °C (890 °C)
- Desired Excess Air Fraction at FB1 → 0.1
- Desired Gas Exit Temperature at ECON2 → 168 °C
- Macro Editor: Lower Limit → 8000
  Upper Limit → 9000

Desired exhaust gas temperature at boiler furnace (FB1) was inputted significantly reduced in both cases, values from operating data list are stated in brackets. The reason is that with given operating exhaust gas temperature at boiler furnace and fuel LHVs, modelled boiler output exhaust gas temperature (Gas Exit Temperature at ECON2) would be higher than 300 °C and boiler fuel consumption would widely increase as well. Another reason is that boiler furnace exhaust gas temperature is theoretical, and it may vary a lot in operating practice.

3.4 Model Reports and Results

After the simulation run, model successfully converged in all cases. As it was already said, due to lack of more detailed information about particular steam boiler equipment, the only evaluated parameter is boiler fuel consumption at production of 120 t of steam per hour. The comparison between GateCycle calculated results with different supplied fuels and given operating data is shown in Table 4. Comprehensive reports summing all streams sorted by equipment are listed in Appendix B - GateCycle stream reports by equipment.

Table 4: Boiler steam production and fuel consumption

	Steam production			Fuel consumption			
	Operating data	GateCycle	Δ	Operating data		GateCycle	Δ
	kg/hr	kg/hr	%	Nm^3/hr	kg/hr	kg/hr	%
Natural gas	120000	120000	+0.000	9755	6980.9	7028.4	+0.68
Tar heating oil	120000	120005	+0.004	-	9079	10244.7	+12.84
Heavy fuel oil	120000	120006	+0.005	-	7670	8643.5	+12.69

Given Boiler operating data states natural gas consumption as 9755 Nm^3/hr which was calculated into kg/hr by equations:

$$\dot{n}_F = \dot{V}_F \left[\frac{Nm^3}{hr}\right] \cdot \frac{1}{V_m} \left[\frac{kmol}{Nm^3}\right] = \frac{9755}{22.414} \doteq 435.2 \left[\frac{kmol}{hr}\right]$$

$$\dot{m}_F = \dot{n}_F \left[\frac{kmol}{hr}\right] \cdot MW \left[\frac{kg}{kmol}\right] = 435.2 \cdot 16.04 \doteq 6980.9 \left[\frac{kg}{hr}\right]$$

Fuel mass flow was calculated with respect to standard SI reference conditions (0 °C, 101.325 kPa) which were inputted into GateCycle properties. GateCycle simulates boiler steam production which is only 0.000 ÷ 0.005 % higher compared to real conditions. That corresponds to tolerance of used macro (0.01 %).

On the one hand, abovementioned steam production was achieved at natural gas consumption rate of 7028.4 kg/hr which is only 0.68 % higher than given theoretical operating consumption rate. GateCycle computational accuracy in this particular case seems to be relatively precise.

On the other hand, calculations with other fuels were relatively inaccurate. Differences with tar heating oil and heavy fuel oil consumption were 12.84 and 12.69 %, respectively. Thesis author's opinion is that it may be caused by questionable values of fuels LHV. As it is mentioned in subchapter "3.1 Description of simulated industrial steam boiler", stated LHV of fuel gas is definitely too low (32 510 kJ/kg) and, therefore, we have let GateCycle to calculate the LHV from molar composition of natural gas (50 044 kJ/kg). After this step, simulated results seem to be relatively highly accurate. Other fuels LHV were not able to be calculated by GateCycle and were used directly as fuel specifications. The lower defined value of fuel LHV generates higher fuel consumption and lower feasible boiler furnace exhaust gas temperature at constant temperature of boiler output exhaust gas temperature.

4 Conclusion

Main aim of this thesis was to get acquainted with General Electric Company GateCycle software which was unfamiliar to our department beforehand and its subsequent application to simulate a specific energy system. Industrial steam boiler producing 120 t of steam per hour was chosen as a representative energy system to be simulated. After first thesis consultation, it had been decided that thesis was to be designed in a form of potential teaching material which might be used in undergraduate course focused on the simulation software.

The first part of the thesis introduces a focus area of process engineers and the necessity of using simulations in practice. Brief insight into how simulation software works and a short list of few of the most well-known process engineering simulation programs were presented.

The second part was dedicated to GateCycle introduction. In the beginning of the chapter, software workspace and interface were shown, followed by thorough guide on how to build a new model, supply input data, run the simulation and obtain the model reports with actual results. In the end of the chapter, short manual how to set macros together with GateCycle preset model library designated mainly for learning purposes were listed.

The third part was dealing with practical part of the thesis - simulating industrial steam boiler with production of 120 t of steam per hour in GateCycle environment. Chapter started with a brief boiler introduction - boiler simple schematic drawing containing main equipment, followed by fuel specifications. More detailed operating data were listed in “Appendix A - Detailed steam boiler specification”. Then, a step-by-step process of boiler model building and input data supplying was comprehensively described, accompanied by GateCycle screenshots. In the end, simulation results were reported and calculated boiler fuel consumptions were compared to real operating data.

Accuracy of calculated natural gas consumption was relatively high, it was just 0.68 % higher than the real consumption. However, results of simulation of operating conditions with tar heating oil and heavy fuel oil were far more imprecise (higher by 12.84 and 12.69 %, respectively) which was probably caused by inaccurate given values of fuel LHVs. It is necessary to mention that due to unknown boiler energy losses, simulated losses values were guessed based on similar operating conditions of other industrial boiler equipment in practice.

To summarise, GateCycle is an intuitive and very flexible tool to model power energy systems. By modelling industrial steam boiler, wide range of simulation options offered by GateCycle were not even fully utilised. GateCycle main “strength” is a power-plant design and analysis of power systems and cogeneration stations with focus on operating performance, overall cycle efficiency and power. GateCycle offers a range of gas turbine modelling options such as “Standard” Gas Turbine model with its library of engines or the Data Gas Turbine, either with entering manufacturer data for a single operating point or using correction curves.

In the future, it could be interesting to investigate more the possibilities that GateCycle provides and utilise the software in area of focus of Institute of Process Engineering (IPE) at Brno University of Technology (BUT). For instance, a model of waste incinerator plant could be built with approximated LHV of supplied waste used as input into fuel specification. A further examination of process equipment design accuracy in GateCycle calculations may be considerable as well. For example, individual heat exchangers heat transfer area and effectiveness in different operating conditions could be modelled and compared with different simulation software outputs such as HTRI or others.

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List of Appendices

Paper Appendices (see following pages):

- Appendix A - Detailed steam boiler specification
- Appendix B - GateCycle stream reports by equipment

Electronic Appendix (see enclosed CD):

- Appendix C - GateCycle steam boiler model

Appendix A - Detailed steam boiler specification

2. **TECHNICKÉ ÚDAJE KOTLE S PŘÍSLUŠENSTVÍM**

2.1. Technické údaje kotle

Jmenovitý výkon kotle	120 t/h
Teplota přehřáté páry	375 + 25°C - 10°C
Tlak přehřáté páry	3,82 MPa
Teplota napájecí vody	145°C

Přehled výpočtových hodnot kotle (tabulky)

Poznámka:

Výpočtové hodnoty uvedené v tomto bodě jsou stanoveny na základě určitých zjednodušení a předpokladů , které ve skutečném provoze nejsou nikdy zcela splněny.Z tohoto důvodu budou skutečné provozní hodnoty vykazovat určité odchylky od výpočtových hodnot.

ZÁKLADNÍ ÚDAJE		*Použité palivo*		
Vybrané veličiny	Rozměr	DTS 100%	PLYN 100%	TTO 100%
Parní výkon	t/h	120	120	120
Tlak přehřáté páry	MPa	3,82	3,82	3,82
Teplota přehř.páry	C°	375	375	375
Teplota nap.vody	C°	145	145	145
Množství vody přes ohř. vody	kg/h	112900	108570	112860
Množství páry přes PŘ 1	kg/h	112900	108570	112860
Množství vstřiku	kg/h	7100	11430	7140
Množství páry přes přes PŘ 2	kg/h	120000	120000	120000

Teplota vody před ohř. vody	C^{o}	145	145	145
Teplota vody za ohř. vody	C^{o}	250	253	243
Teplota v bubnu	C^{o}	254	254	254
Teplota páry za PŘ1	C^{o}	327	340	326
Teplota páry za vstř	C^{o}	277	260	276
Teplota páry za PŘ 2	C^{o}	375	375	375
Střední rychlost vody v ohř.v.	m/s	1,2	1,1	1,2
Stř.rychl.páry v PR 1	m/s	19	19	19
Stř.rychl.pary v PR 2	m/s	24	23	24
Mn.vzduchu do do hořáků	Nm^{3}/h	101438	104403	94608
Mn.spalin za spal.komorou	Nm^{3}/h	113725	115187	108890
Mn.spal.recikl.	Nm^{3}/h	12185	4430	11667
Tepl.vzduchu nasávaného	C^{o}	30	30	30
Tepl.vzd.za POV	C^{o}	130	130	130
Tepl.spal.v jádru plamene	C^{o}	1783	1771	1851
Tepl. spal. za spal.komorou	C^{o}	872	957	890
Tepl.spal.za PR 2	C^{o}	637	663	635
Tepl.spal.za PR 1	C^{o}	477	487	470
Tepl.spal.za ohř. vody	C^{o}	170	170	168
Tepl.spal.za kotlem	C^{o}	170	170	168

Stř.rychl.spalin v mříži	m/s	16	17	15,5
Stř.rychl.spalin v PR 2	m/s	13	14	12
Stř.rychl.spalin v PR 1	m/s	11	11	10
Stř.rychl.spalin v ohř. vody	m/s	8	8	7

PŘEBYTKY VZDUCHU				
Ve vzd.v hořácích	-	1,1	1,06	1,1
Ve spalirnách za spal. kom.	-	1,1	1,06	1,1

ÚČINNOST A MNOŽSTVÍ PALIVA		DTS	PLYN	TTO
Účinnost kotle	%	93	92	94
Množství paliva	kg/h	9079	-	7670
Množství paliva	Nm^3/h	-	9755	-

Technické podmínky záruk

Napájecí voda **Kotelní voda**

Tvrdost	10 mikroval/l	vodivost	2 700 uS/cm^2
O_2	20 mikrog/l	P_2O_5	5-12 mg/l
Fe	50 mikrog/l		
pH	8,5 - 9,5		
olej	0,5 mg/l		

Paliva

a) Dehtová topná směs (teer olej)

- výhřevnost 34 200 kj/kg
- složení :

C	94 %
H_2	5 %
S	0,5 %
Na	0,05 %
Ca	0,004 %
Cr	0,003 %
Ni	0,001 %

Cu	0,007	%
Zn	0,0001	%
Hg	0,00001	%
N_2	0,6	%
popeloviny	0,2	%
O_2	1	%

b) Zemní plyn

-výhřevnost	32 510	kj/kg
-složení : CH_4	97,8	%
C_2H_6 a vyšší uhlovodíky	1,1	%
S	0,3	mg/m3
$CO_2 + N_2$	1,1	%

c) Těžký topný olej (TTO)

-výhřevnost	40 612	kj/kg
-složení : H_2O	1	%
S	2,35	%
mech.nečistoty	1	%

Záruky

Parametry kotle

a) Při spalování dehtové topné směsi

Jmenovitý výkon kotle	120 t/h
Jmenovitý tlak přehřáté páry	3,82 MPa
Jmenovitý teplota přehř. páry	375 ^{0}C
Teplota přehř.páry v rozmezí	50-100 %
Účinnost kotle při teplotě okolního vzduchu 20 ^{0}C a při jmenovitém výkonu	93,0 %

b) Při spalování plynu

Jmenovitý výkon kotle	120 t/h
Jmenovitý tlak přehřáté páry	3,82 MPa
Účinnost kotle při teplotě okolního vzduchu 20 ^{0}C a při jmenovitém výkonu	92,0 %

c) Při spalování oleje (TTO)

Jmenovittý výkon kotle	120 t/h
Jmenovitý tlak přehř.páry	3,82 MPa
Jmenovitá teplota přehř.páry	375 ^{0}C
Teplota přehř.páry v rozmezí	50-100 %
Účinnost kotle při teplotě okolního vzduchu 20 ^{0}C a při jmenovitém výkonu	94,0 %

Čistota páry

Měrná el.vodivost při 25 ^{0}C	0,3 mikroS/cm
Obsah SiO_2	40 mikrog/l

Obsah Fe	10 mikrog/l
Obsah Na+ + K+	10 mikrog/l

Obsah CO ve spalinách

Vztažený na suchý plyn v normálním stavu a na objemový obsah O_2 - 3 %

- max.170 mg/m^3 při provozu na TTO a DTS
- max.100 mg/m^3 při provozu na zemní plyn

Obsah NO_x ve spalinách

Počítané jako NO_2, vztažené na suchý plyn a na objemový obsah O_2 - 3 %.
- max.450 mg/m^3 při provvozu na TTO a DTS
- max.200 mg/m^3 při provozu na zemní plyn

Regulační rozsah hořáku 1 : 5

Velikost výhřevných ploch

EKO vnitřní	cca 1 317 m^2
EKO vnější	cca 2 268 m^2
Výparník	cca 2 169 m^2
Přehřívák I	cca 378 m^2
Přehřívák II	cca 603 m^2

Objem tlakového systému kotle

EKO vnitřní	6,37 m^3
EKO vnější	10,43 m^3
Výparník	33,6 m^3
Buben	17,4 m^3
Přehříváky	5,9 m^3
Spojovací potrubí	1,71 m^3
celkem	75,41 m^3

Čistota napájecí vody

tvrdost	10 mikroval/l
obsah O2	20 mikrog/l
pH	8,5-9,5
olej	5 mg/l
obsah CO2	50 mikrog/l
obsah Fe	

Čistota kotelní vody

vodivost	2 700 mikro S/cm
zjevná alkalita p	1-5 mval/l
rozp.P2 O5	5-12 mg/l
obsah SiO2	20 mg/l

Vstřiková voda

obsah SiO2	10-50 mikrog/l
vodivost	0,5-2 mikro S/cm

TECHNICKÉ ÚDAJE O ZAŘÍZENÍCH PŘÍSLUŠENSTVÍ KOTLE.

1. **Impulzní pojistné ventily**

Počet pro 1 kotel		2
Typ	SIZ	1508
JS	100	150
Otvírací tlak	4,3 MPa	4,6 MPa
Teplota páry	375 ^{0}C	
Výkon	62 t/h	66 t/h

2. **Parní ohřívák vzduchu**

Počet pro 1 kotel	2
Typ	kruhově žebrované trubky
Celková výhřevná plocha	1780 m^2
Počet řad trubek	24
Celkový počet sekcí	4

Parametry v závislosti na výkonu kotle :

Výkon kotle:		100 %	80 %
Teplota vzduchu na vstupu	^{0}C	25	25
Teplota vzduchu na výstupu	^{0}C	130	125
Množství vzduchu na kotel	Nm^3/h	104500	83600
Teplota páry	^{0}C	210	210
Tlak páry	MPa	0,6	0,6
Celková spotřeba páry	kg/h	8695,3	6634,2

3. **Vzduchový ventilátor**

Počet pro 1 kotel:	2 ks
Typ:	radiální RVK 1600
Dopravované množství:	20 m^3/s
Teplota média	20 ^{0}C
Měrná hmotnost	1,2 kg/m^3
Celkový tlak	8500 Pa
Otáčky	1485 ot/min
Typ el.motoru:	AF 355-M-4
parametry:	250 kW, 380 V, 1485 l/min

4. **Recirkulační ventilátory**

Počet pro 1 kotel:	2 ks
Typ:	radiální RVK 1250
Dopravované množství:	6 m^3/s
Teplota média	314 ^{0}C
Celkový tlak	4200 Pa
Otáčky	1475 ot/min

Typ el. motora: F 225 MO4,45 kW, 1460 ot/min. 380/220

5.Parní ofukovače kotle

	2 tah	3tah
Počet pro 1 kotel	6	3
Typ:	PS 85-E	PSB 85 E
Převodovka:	SP 118	SP 118
El.motor	FD 80N 12-4 0,55kW ,1390 ot/min 50Hz ,220/380 V	FD 71N 13-4 0,37kW ,1380 ot/min ,50Hz, 220/380 V

Parametry páry před redukční stanicí: 38 bar, 375^{0}C

Technické údaje ofukovače:	PS 85 E NVO4 D100- -NV09 D100	PSB 85 E NV11 D100 NV13 D100 NV15 D100
Celková výsuvná délka	2400 mm	1300 mm
Celková doba činnosti	199 s	188 s
Délka vysunutí při ofukování	2065 mm	1055 mm
Čistý čas ofukování	171 s	176 s
Tlak páry před tryskou	16 bar	16 bar
Průměr trysky	22,5 mm	16 mm
Počet trysek	2	4
Průtokové množství páry	1,48 kg/s	1,48 kg/s
Spotřeba páry pro 1 ofukovaač	258 kg	260 kg
Celková spotřeba páry pro 1 cyklus		1518 kg
Celkový čas		20 min.

6.Kombinované hořáky - fy Deutche BABCOCK

Nízkoemisní kombinované hořáky z parním rozprašováním
4 ks
typ: AS BR-A-K-13-420

Výkon hořáku pro jednotlivé paliva :

Palivo	TTO
Minimální výkon	1925 kg/h
Maximální výkon	2050 kg/h
Tlak	17 bar
Teplota	140^{0}C
Výhřevnost	40 610 kj/kg

Palivo	DTS
Minimální výkon	2275 kg/h
Maximální výkon	2500 kg/h
Tlak	17 bar
Teplota	230^{0}C
Výhřevnost	34 200 kj/kg
Palivo	Zemní plyn
Minimální výkon	2 450 Nm^3/h
Maximální výkon	2 625 Nm^3/h
Tlak	1,7 bar
Teplota	20^{0}C
Výhřevnost	32 510 kj/kg

Appendix B - GateCycle stream reports by equipment

Stream report by equipment with natural gas as a fuel

Equipment/Ports	Flow kg/h	Pressure kPa	Temperature °C	Enthalpy kJ/kg	Quality -
AIR [GAS]: GAS					
Outlet	123834.6	101.3	130.0	115.4	1
C1 [GTCOMP]: Compressor					
Inlet	123834.6	101.3	130.0	115.4	1
Main Outlet	123834.6	101.3	130.0	115.4	1
C2 [GTCOMP]: Compressor					
Inlet	15516.2	101.3	438.8	486.7	0
Main Outlet	15516.2	105.0	447.2	496.9	1
DA1 [DEAER]: Deaerator					
Main Steam Inlet	314.8	200.0	120.2	2706.3	1
Main Boiler Feed Water Inlet	120887.8	200.0	20.0	84.0	0
Main Boiler Feed Water Outlet	135716.0	101.3	100.0	419.1	0
Auxiliary Steam Inlet	14513.4	3820.0	375.0	3159.9	1
Vent Steam Outlet	0.0	101.3	100.0	2676.0	1
DRUM BLOWDOWN [SINK]: Sink					
Inlet	886.5	200.0	120.2	504.7	0
DRUM1 [DRUM]: Drum					
Primary Return	132299.2	3920.0	249.1	2625.3	0.898
Main Water Outlet	132299.2	3920.0	249.1	1081.6	0
Main Boiler Feed Water Inlet	121335.6	4200.0	253.0	1100.4	0
Main Steam Outlet	120133.5	3920.0	249.1	2800.7	1
Blowdown	1201.3	3920.0	249.1	1081.6	0
ECON1 [ECON]: Economizer					
Gas Inlet	146379.2	101.3	562.6	639.2	0
Gas Outlet	146379.2	101.3	438.8	486.7	0
Water Inlet	121335.6	4300.0	213.9	916.5	0
Water Outlet	121335.6	4200.0	253.0	1100.4	0
ECON2 [ECON]: Economizer					
Gas Inlet	130863.0	101.3	438.8	486.7	0
Gas Outlet	130863.0	101.3	170.0	172.0	0

Water Inlet	135716.0	4400.0	145.0	613.1	0
Water Outlet	135716.0	4300.0	213.9	916.5	0
EXH1 [EXH]: EXH					
Inlet	130863.0	101.3	170.0	172.0	0
FB1 [FBOILR]: Fossil Boiler					
Primary Air Inlet	0.0	101.3	130.0	115.4	1
Secondary Air Inlet	123834.6	101.3	130.0	115.4	1
Recycle Air Inlet	15516.2	105.0	447.2	496.9	1
Flue Gas Outlet	146379.2	101.3	957.0	1154.5	0
Evaporator Inlet	132299.2	3920.0	249.1	1081.6	0
Evaporator Outlet	132299.2	3920.0	249.1	2625.3	0.898
Fuel Gas Inlet	7028.4	170.0	20.0	9.6	1
FEED WATER [MAKEUP]: Makeup					
Outlet	120887.8	200.0	20.0	84.0	0
FL1 [FLASH]: Flash Tank					
Main Inlet	1201.3	3920.0	249.1	1081.6	0
Gas or Steam Outlet	314.8	200.0	120.2	2706.3	1
Water Outlet	886.5	200.0	120.2	504.7	0
Condensate Outlet	0.0	200.0	120.2	504.7	0
FUEL [GAS]: GAS					
Outlet	7028.4	170.0	20.0	9.6	1
HDR1 [HEADER]: Header					
First Inlet	134513.8	3820.0	375.0	3159.9	1
First Outlet	14513.4	3820.0	375.0	3159.9	1
Eighth Outlet	120000.4	3820.0	375.0	3159.9	1
PUMP1 [PUMP]: Pump					
Main Inlet	135716.0	101.3	100.0	419.1	0
Control Valve Outlet	135716.0	4400.0	100.5	424.3	0
Internal Pump Flow	135716.0	101.3	100.0	419.1	0
SP1 [SPLITR]: Splitter					
Inlet	146379.2	101.3	438.8	486.7	0
Primary Outlet	130863.0	101.3	438.8	486.7	0
Secondary Outlet	15516.2	101.3	438.8	486.7	0
SP2 [SPLITR]: Splitter					
Inlet	123834.6	101.3	130.0	115.4	1
Primary Outlet	0.0	101.3	130.0	115.4	1

Tertiary Outlet	123834.6	101.3	130.0	115.4	1
SP3 [SPLITR]: Splitter					
Inlet	135716.0	4300.0	213.9	916.5	0
Primary Outlet	14380.3	4300.0	213.9	916.5	0
Secondary Outlet	121335.6	4300.0	213.9	916.5	0
SPHT1 [SPHT]: Superheater					
Gas Inlet	146379.2	101.3	957.0	1154.5	0
Gas Outlet	146379.2	101.3	737.6	862.8	0
Steam Inlet	134513.8	3870.0	260.0	2842.5	1
Steam Outlet	134513.8	3820.0	375.0	3159.9	1
SPHT2 [SPHT]: Superheater					
Gas Inlet	146379.2	101.3	737.6	862.8	0
Gas Outlet	146379.2	101.3	562.6	639.2	0
Steam Inlet	120133.5	3920.0	249.1	2800.7	1
Steam Outlet	120133.5	3870.0	340.0	3073.0	1
STEAM PRODUCTION [SINK]: Sink					
Inlet	120000.4	3820.0	375.0	3159.9	1
TMX1 [TMIX]: Temperature Control Mixer					
Main Inlet	120133.5	3870.0	340.0	3073.0	1
Outlet	134513.8	3870.0	260.0	2842.5	1
Control Inlet	14380.3	4300.0	213.9	916.5	0
V1 [PIPVLV]: Valve					
Inlet	14513.4	3820.0	375.0	3159.9	1
Outlet	14513.4	3820.0	375.0	3159.9	1
V2 [PIPVLV]: Valve					
Inlet	135716.0	4400.0	100.5	424.3	0
Outlet	135716.0	4400.0	145.0	613.1	0
V3 [PIPVLV]: Valve					
Inlet	134513.8	3820.0	375.0	3159.9	1
Outlet	134513.8	3820.0	375.0	3159.9	1

Stream report by equipment with tar heating oil as a fuel

Equipment/Ports	Flow kg/h	Pressure kPa	Temperature °C	Enthalpy kJ/kg	Quality -
AIR [GAS]: GAS					
Outlet	187016.5	101.3	130.0	115.4	1
C1 [GTCOMP]: Compressor					
Inlet	187016.5	101.3	130.0	115.4	1
Main Outlet	187016.5	101.3	130.0	115.4	1
C2 [GTCOMP]: Compressor					
Inlet	23636.0	101.3	352.0	381.7	0
Main Outlet	23636.0	105.0	359.6	390.6	1
DA1 [DEAER]: Deaerator					
Main Steam Inlet	329.0	200.0	120.2	2706.3	1
Main Boiler Feed Water Inlet	120930.4	200.0	20.0	84.0	0
Main Boiler Feed Water Outlet	135766.2	101.3	100.0	419.1	0
Auxiliary Steam Inlet	14506.8	3820.0	375.0	3159.9	1
Vent Steam Outlet	0.0	101.3	100.0	2676.0	1
DRUM BLOWDOWN [SINK]: Sink					
Inlet	926.5	200.0	120.2	504.7	0
DRUM1 [DRUM]: Drum					
Primary Return	139457.4	3920.0	249.1	2625.3	0.898
Main Water Outlet	139457.4	3920.0	249.1	1081.6	0
Main Boiler Feed Water Inlet	126796.1	4200.0	250.0	1085.8	0
Main Steam Outlet	125541.3	3920.0	249.1	2800.7	1
Blowdown	1255.4	3920.0	249.1	1081.6	0
ECON1 [ECON]: Economizer					
Gas Inlet	220897.2	101.3	432.6	477.9	0
Gas Outlet	220897.2	101.3	352.0	381.7	0
Water Inlet	126796.1	4300.0	214.3	918.3	0
Water Outlet	126796.1	4200.0	250.0	1085.8	0
ECON2 [ECON]: Economizer					
Gas Inlet	197261.2	101.3	352.0	381.7	0
Gas Outlet	197261.2	101.3	170.0	171.6	0
Water Inlet	135766.2	4400.0	145.0	613.1	0
Water Outlet	135766.2	4300.0	214.3	918.3	0

EXH1 [EXH]: EXH					
Inlet	197261.2	101.3	170.0	171.6	0
FB1 [FBOILR]: Fossil Boiler					
Primary Air Inlet	0.0	101.3	130.0	115.4	1
Secondary Air Inlet	187016.5	101.3	130.0	115.4	1
Recycle Air Inlet	23636.0	105.0	359.6	390.6	1
Flue Gas Outlet	220897.2	101.3	670.0	773.1	0
Evaporator Inlet	139457.4	3920.0	249.1	1081.6	0
Evaporator Outlet	139457.4	3920.0	249.1	2625.3	0.898
Fuel Gas Inlet	10244.7	1700.0	230.0	532.6	1
FEED WATER [MAKEUP]: Makeup					
Outlet	120930.4	200.0	20.0	84.0	0
FL1 [FLASH]: Flash Tank					
Main Inlet	1255.4	3920.0	249.1	1081.6	0
Gas or Steam Outlet	329.0	200.0	120.2	2706.3	1
Water Outlet	926.5	200.0	120.2	504.7	0
Condensate Outlet	0.0	200.0	120.2	504.7	0
FUEL [GAS]: GAS					
Outlet	10244.7	1700.0	230.0	532.6	1
HDR1 [HEADER]: Header					
First Inlet	134511.4	3820.0	375.0	3159.9	1
First Outlet	14506.8	3820.0	375.0	3159.9	1
Eighth Outlet	120004.8	3820.0	375.0	3159.9	1
PUMP1 [PUMP]: Pump					
Main Inlet	135766.2	101.3	100.0	419.1	0
Control Valve Outlet	135766.2	4400.0	100.5	424.3	0
Internal Pump Flow	135766.2	101.3	100.0	419.1	0
SP1 [SPLITR]: Splitter					
Inlet	220897.2	101.3	352.0	381.7	0
Primary Outlet	197261.2	101.3	352.0	381.7	0
Secondary Outlet	23636.0	101.3	352.0	381.7	0
SP2 [SPLITR]: Splitter					
Inlet	187016.5	101.3	130.0	115.4	1
Primary Outlet	0.0	101.3	130.0	115.4	1
Tertiary Outlet	187016.5	101.3	130.0	115.4	1

SP3 [SPLITR]: Splitter					
Inlet	135766.2	4300.0	214.3	918.3	0
Primary Outlet	8970.1	4300.0	214.3	918.3	0
Secondary Outlet	126796.1	4300.0	214.3	918.3	0
SPHT1 [SPHT]: Superheater					
Gas Inlet	220897.2	101.3	670.0	773.1	0
Gas Outlet	220897.2	101.3	543.6	613.7	0
Steam Inlet	134511.4	3870.0	277.0	2898.2	1
Steam Outlet	134511.4	3820.0	375.0	3159.9	1
SPHT2 [SPHT]: Superheater					
Gas Inlet	220897.2	101.3	543.6	613.7	0
Gas Outlet	220897.2	101.3	432.6	477.9	0
Steam Inlet	125541.3	3920.0	249.1	2800.7	1
Steam Outlet	125541.3	3870.0	327.0	3039.7	1
STEAM PRODUCTION [SINK]: Sink					
Inlet	120004.8	3820.0	375.0	3159.9	1
TMX1 [TMIX]: Temperature Control Mixer					
Main Inlet	125541.3	3870.0	327.0	3039.7	1
Outlet	134511.4	3870.0	277.0	2898.2	1
Control Inlet	8970.1	4300.0	214.3	918.3	0
V1 [PIPVLV]: Valve					
Inlet	14506.8	3820.0	375.0	3159.9	1
Outlet	14506.8	3820.0	375.0	3159.9	1
V2 [PIPVLV]: Valve					
Inlet	135766.2	4400.0	100.5	424.3	0
Outlet	135766.2	4400.0	145.0	613.1	0
V3 [PIPVLV]: Valve					
Inlet	134511.4	3820.0	375.0	3159.9	1
Outlet	134511.4	3820.0	375.0	3159.9	1

Stream report by equipment with heavy fuel oil as a fuel

Equipment/Ports	Flow kg/h	Pressure kPa	Temperature °C	Enthalpy kJ/kg	Quality -
AIR [GAS]: GAS					
Outlet	157801.9	101.3	130.0	115.4	1
C1 [GTCOMP]: Compressor					
Inlet	157801.9	101.3	130.0	115.4	1
Main Outlet	157801.9	101.3	130.0	115.4	1
C2 [GTCOMP]: Compressor					
Inlet	19735.1	101.3	400.2	439.0	0
Main Outlet	19735.1	105.0	408.3	448.6	1
DA1 [DEAER]: Deaerator					
Main Steam Inlet	328.6	200.0	120.2	2706.3	1
Main Boiler Feed Water Inlet	120930.1	200.0	20.0	84.0	0
Main Boiler Feed Water Outlet	135765.7	101.3	100.0	419.1	0
Auxiliary Steam Inlet	14507.1	3820.0	375.0	3159.9	1
Vent Steam Outlet	0.0	101.3	100.0	2676.0	1
DRUM BLOWDOWN [SINK]: Sink					
Inlet	925.3	200.0	120.2	504.7	0
DRUM1 [DRUM]: Drum					
Primary Return	142059.2	3920.0	249.1	2625.3	0.898
Main Water Outlet	142059.2	3920.0	249.1	1081.6	0
Main Boiler Feed Water Inlet	126642.0	4200.0	243.0	1052.0	0
Main Steam Outlet	125389.1	3920.0	249.1	2800.7	1
Blowdown	1253.9	3920.0	249.1	1081.6	0
ECON1 [ECON]: Economizer					
Gas Inlet	186180.6	101.3	461.4	512.7	0
Gas Outlet	186180.6	101.3	400.2	439.0	0
Water Inlet	126642.0	4300.0	219.9	943.6	0
Water Outlet	126642.0	4200.0	243.0	1052.0	0
ECON2 [ECON]: Economizer					
Gas Inlet	166445.4	101.3	400.2	439.0	0
Gas Outlet	166445.4	101.3	168.0	169.3	0
Water Inlet	135765.7	4400.0	145.0	613.1	0
Water Outlet	135765.7	4300.0	219.9	943.6	0

EXH1 [EXH]: EXH					
Inlet	166445.4	101.3	168.0	169.3	0
FB1 [FBOILR]: Fossil Boiler					
Primary Air Inlet	0.0	101.3	130.0	115.4	1
Secondary Air Inlet	157801.9	101.3	130.0	115.4	1
Recycle Air Inlet	19735.1	105.0	408.3	448.6	1
Flue Gas Outlet	186180.6	101.3	740.0	863.3	0
Evaporator Inlet	142059.2	3920.0	249.1	1081.6	0
Evaporator Outlet	142059.2	3920.0	249.1	2625.3	0.898
Fuel Gas Inlet	8643.5	1700.0	140.0	290.1	1
FEED WATER [MAKEUP]: Makeup					
Outlet	120930.1	200.0	20.0	84.0	0
FL1 [FLASH]: Flash Tank					
Main Inlet	1253.9	3920.0	249.1	1081.6	0
Gas or Steam Outlet	328.6	200.0	120.2	2706.3	1
Water Outlet	925.3	200.0	120.2	504.7	0
Condensate Outlet	0.0	200.0	120.2	504.7	0
FUEL [GAS]: GAS					
Outlet	8643.5	1700.0	140.0	290.1	1
HDR1 [HEADER]: Header					
First Inlet	134512.8	3820.0	375.0	3159.9	1
First Outlet	14507.1	3820.0	375.0	3159.9	1
Eighth Outlet	120005.9	3820.0	375.0	3159.9	1
PUMP1 [PUMP]: Pump					
Main Inlet	135765.7	101.3	100.0	419.1	0
Control Valve Outlet	135765.7	4400.0	100.5	424.3	0
Internal Pump Flow	135765.7	101.3	100.0	419.1	0
SP1 [SPLITR]: Splitter					
Inlet	186180.6	101.3	400.2	439.0	0
Primary Outlet	166445.4	101.3	400.2	439.0	0
Secondary Outlet	19735.1	101.3	400.2	439.0	0
SP2 [SPLITR]: Splitter					
Inlet	157801.9	101.3	130.0	115.4	1
Primary Outlet	0.0	101.3	130.0	115.4	1
Tertiary Outlet	157801.9	101.3	130.0	115.4	1

SP3 [SPLITR]: Splitter					
Inlet	135765.7	4300.0	219.9	943.6	0
Primary Outlet	9123.7	4300.0	219.9	943.6	0
Secondary Outlet	126642.0	4300.0	219.9	943.6	0
SPHT1 [SPHT]: Superheater					
Gas Inlet	186180.6	101.3	740.0	863.3	0
Gas Outlet	186180.6	101.3	590.2	671.9	0
Steam Inlet	134512.8	3870.0	276.0	2895.1	1
Steam Outlet	134512.8	3820.0	375.0	3159.9	1
SPHT2 [SPHT]: Superheater					
Gas Inlet	186180.6	101.3	590.2	671.9	0
Gas Outlet	186180.6	101.3	461.4	512.7	0
Steam Inlet	125389.1	3920.0	249.1	2800.7	1
Steam Outlet	125389.1	3870.0	326.0	3037.1	1
STEAM PRODUCTION [SINK]: Sink					
Inlet	120005.9	3820.0	375.0	3159.9	1
TMX1 [TMIX]: Temperature Control Mixer					
Main Inlet	125389.1	3870.0	326.0	3037.1	1
Outlet	134512.8	3870.0	276.0	2895.1	1
Control Inlet	9123.7	4300.0	219.9	943.6	0
V1 [PIPVLV]: Valve					
Inlet	14507.1	3820.0	375.0	3159.9	1
Outlet	14507.1	3820.0	375.0	3159.9	1
V2 [PIPVLV]: Valve					
Inlet	135765.7	4400.0	100.5	424.3	0
Outlet	135765.7	4400.0	145.0	613.1	0
V3 [PIPVLV]: Valve					
Inlet	134512.8	3820.0	375.0	3159.9	1
Outlet	134512.8	3820.0	375.0	3159.9	1